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User Haptic Experience: Transferring Real World Tactile Sensation of Drawing Tools Into Haptic Interfaces

Suziah Sulaiman

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Declaration

I, Suziah Sulaiman, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

Abstract

Haptic perception is context dependent, suggesting that haptic cues in one particular domain of applications may not be suitable for another. Literature suggests that options should be given to users to allow customisation of feedback received to fit their needs. How these options should be presented has not been investigated. Also, little has been reported with respect to haptic cues in drawing, a fundamental domain in art.

This research explores haptic sensations that artists recognise in a drawing environment and investigates design representations to support those sensations. It addresses these inter-related questions: (1) What are the haptic features involved in drawing? (2) What haptic cues are suitable for a drawing application and how to integrate them? (3) In such an application, do users prefer to interact with an interface design that has a "fixed haptic" sensation or its "variable haptic" counterpart? (4) If a variable haptic design is preferred, do users prefer to interact with haptic information represented in the system using an interface metaphor that involves a real world object-based representation whose underlying haptic sensation feels similar to its real world counterpart, or a textual description of the underlying feature that corresponds to an intuitive haptic sensation? These questions were addressed in three practical aspects of research work: a study to capture the design requirements, implementation of the haptic interfaces, and a main evaluation study.

The first study resulted in a taxonomy of haptic cues for drawing. The haptic cues for a drawing application were integrated into two different types of interface. The integration was motivated by the role and reification of metaphor to make haptic information concrete. An evaluation study tested users' preferences on these design representations suggesting a preference for a variation of force feedback. The findings suggest that both designs have potential to be accepted by users.

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This thesis is dedicated to my father, in loving memory.

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Chapter 1 Introduction

The term 'haptic' comes from a Greek word haptesthai, meaning, "to touch". It has been associated to the science of applying touch (tactile) sensation and control to interaction with computer applications. Recent developments in interface design have utilised an understanding of the human sense of touch whereby the subjective user experience and perception interacting in the real world is examined and integrated in a computer environment. A preferred tactile sensation as perceived by the users with respect to the application developed could increase the realism of an interaction.

This thesis explores the area of user haptic perception and interface design for a drawing environment. As the success of a haptic integration in a system is largely dependent on user acceptance, it is necessary to investigate users' subjective preferences on both haptic perception and interfaces. The vision behind the idea of integrating haptic feedback in a drawing application consists of two central goals. The first is to present an appropriate haptic design representation preferred by the users, and second to create an acceptable haptic sensation during a drawing interaction.

The motivation to investigate users' haptic sensation in a drawing domain is initiated from a claim in the literature that the haptic interface in art-related work is capable of supporting creative processes. Users could feel more creative in their artwork when interacting with such interfaces. Such a claim signals new promises for drawing applications in terms of benefits received from the haptic feedback. However, there are some design challenges that need to be addressed, which includes the type of haptic features suitable for a drawing application. This issue becomes more apparent because unlike other applications such as those for medical training and blind users, the benefits of haptics in a drawing application are less direct. From the belief that haptics could assist in promoting a creative process, the tactile cues received during an interaction are likely to play an important role in determining user preference in terms of haptic sensation in a drawing interface.

As computer haptics could be considered as analogous to computer graphics, the research development of the former is influenced by the approaches used in the latter field. While computer graphics deals with generating and rendering visual images, computer haptics concerns itself with tactile stimuli to the human user. The techniques of computer graphics have become a major part of human-computer interfaces in displaying and manipulating data and objects. Replicating relevant techniques used in a mature field such as computer graphics, and with the growing development of the technology used to build haptic devices, makes haptic feedback increasingly practical for interactions.

In general, studies involving haptic interactions have been approached from two inter-related perspectives: technical and perceptual viewpoints. From the technical side, the topics concerned include investigating the computational aspects of haptic rendering. Mainly the objective is to obtain an efficient rendering and to achieve a realistic haptic sensation. On the other hand, topics involved in the perceptual viewpoint include understanding aspects of the human sensory touch and how users perceive the haptic feedback provided in an application.

1.1 Research Problem

Haptic sensation is very context dependent in the sense that its role varies depending on user preference, the application in question, the device used and the modality involved (Yu and Brewster, 2003). Such dependence has resulted in a situation whereby one particular haptic cue used in a certain domain may not be appropriate to another. This has formed a pattern found in most studies in haptic interactions in which different domains of applications have used different types of cues. At present, no work has been reported in finding a "complete" set of haptic cues whilst interacting in a drawing domain. If haptic feedback could benefit an interaction, a missing cue from this set may hinder users from the feel of being creative, hence jeopardising the user acceptance towards the system being assessed. It is a challenge for a designer in finding the appropriate haptic cues for a drawing environment especially when the benefits of haptics for this domain are less direct.

Yu and Brewster (2003) cautioned on the difficulties in distinguishing force perception, despite the fact that haptic feedback could create a feeling of realism interacting in an environment when appropriately integrated into a system. In general, haptic perception is an individual matter, as a force which is perceived as weak by one person may feel stronger to another. Yu and Brewster suggested that options should be given to the users so that they could customise the feedback according to their needs. This suggestion is particularly useful when dealing with a drawing application because the decision whether a system is to be used or not partly depends on a user's subjective preference towards the haptic sensation felt. As the user's acceptance relies largely on how 'pleasant' (if not 'real') a particular sensation is as perceived during an interaction, providing such options to users could overcome the difficulties in assessing the haptic feedback. However, it is still not clear in the reported work how these options should be presented to the users. It is another challenge to the designer to find out the preferred user interface that should be deployed and on what basis it should be chosen.

1.2 Research Questions

The research problem specified in Section 1.1 has led to a formulation of research questions for this thesis. These questions will be addressed in three inter-related investigations, which involve users' subjective experience in drawing. The first question concerns the overall tactile experience in a drawing environment:

Question 1: What are the haptic features involved in a drawing domain?

This question is addressed in an exploratory study presented in Chapter 3 where the haptic sensation recognise by artists during a drawing interaction is compiled. This leads to the following question, which is concerned with haptic sensations for a drawing application.

Question 2: What are the haptic features suitable for a drawing application?

This question is addressed and presented in Chapter 3 as well. In answering this question, findings obtained from Question 1 are examined to identify haptic features suitable for a drawing application.

Question 3: How do we integrate the haptic features identified in a design interface?

This question is addressed in implementation work presented in Chapter 6. It is related to Question 2 in the sense that the identified haptic features are integrated in a drawing prototype. The implementation involves a simple technique to include haptic feedback in a drawing environment. The main idea is to apply the concept of metaphor in representing haptic information in the drawing prototype.

Question 4: In a drawing application, do users prefer manipulating a "fixed haptic" interface or its "variable haptic" counterpart?

This question is addressed in an evaluation study presented in Chapter 7. In the context of this research project the term "fixed haptic" means the same haptic effect is presented to the users throughout the drawing interaction whereas "variable haptic" means a different haptic feedback is provided based on the features (widgets) selected on the interface. Immediately following from this question is a query pertaining to the variable haptic options.

Question 5: If a variable haptic design is preferred, do users prefer to interact with haptic information represented in a system using an interface metaphor design that involves a:

(i) real world object-based in which underlying haptic sensation feels similar to its real world counterpart, or

(ii) textual description of the underlying feature that corresponds to an intuitive haptic sensation?

This question is also part of the evaluation study presented in Chapter 7. The textual description noted in (ii) will be described in Sections 5.5.2 and 6.4.2. In addressing this question, a conclusion is made in terms of users' preferences when dealing with haptic features in a drawing application and reasons for their choice. The effect of metaphor that represents haptic sensation on user haptic experience is examined.

1.3 Contributions

The main contributions for this research project are listed as follows.

1. An approach in the form of an exploratory investigation to elicit a haptic taxonomy from user experience interacting in the real world (Chapter 3). This contribution shows a way to gather information on the haptic sensation that users recognise in a drawing interaction in the real world.

2. A proposed taxonomy of haptic features for a drawing application (Chapter 3). This contribution compiles users' experiences interacting in the real world environment with their tactual perceptions during such interactions. A set of haptic cues for the drawing domain is focused in order to identify the features suitable to be integrated in a drawing application.

3. An approach to integrate haptic cues obtained from a real world interaction into a computer environment (Chapter 6). This contribution demonstrates a way of implementing two options of design interfaces that could be used in presenting haptic information for a drawing application. Such an implementation assists in preparing an evaluation study that involves investigation of the variable haptic options provided to the users.

4. A demonstration of an empirical evaluation of whether a variable haptic interface design is preferred to its fixed counterpart. This contribution shows an approach to evaluate haptic drawing interfaces whose design was based on concepts of metaphor in representing haptic information. The user haptic experience reported in the study findings could inform designs of haptic interfaces (Chapter 7).

1.4 Scope of the Thesis

In this research project, the drawing domain is chosen to represent an example of an art-related application. This focus is made based on the fact that drawing is a fundamental form of art (Rosand, 2002). This domain is also reported to have potential in supporting interactions (Peters and Healey, 2003), hence a good candidate for this research.

The visual and haptic elements are two important aspects in a drawing process. However, this thesis is concerned particularly with the haptic elements. Its main focus is on users' perceived haptic experience in the drawing domain. The challenge in finding an appropriate feedback for a computer drawing application motivates studying users' tactile experience when drawing in the real world. This research is not concerned, however, with the gestures made during the interactions but with the tactile sensation felt as the pen-like tool touches the drawing surface.

The integration of haptic feedback in a computer environment involves the haptic rendering process. Again, this research is not concerned with the computational aspect of haptic rendering techniques but with the users' perception of the perceived haptic feeling during their drawing interactions. Due to the nature of this research focus, the method to be adopted in this research project will involve mainly a qualitative approach.

1.5 Structure of the Thesis

In brief, Chapters 2, 4 and 5 consist of a relevant literature review for this research project. Chapter 2 focuses on the haptic literature review pertaining to the user aspect of this research project. It provides a background understanding of the research by presenting the existing reported work relating to user experience of haptic sensations. Chapter 4 continues by addressing the technological or system aspect of this research project. It addresses haptic rendering and force perception, and a review of haptic devices and applications developed. Chapter 5 concentrates on the interface aspects which link together the user and system aspects presented in Chapter 2 and 4. This chapter introduces two types of design interfaces that are used in the practical work in this thesis. The design was based on a concept of metaphor to represent abstract haptic information.

This theoretical understanding is brought into practice in Chapters 3, 6 and 7. Chapter 3 presents a study to identify haptic features for a drawing domain. The study involves understanding people's experience in using pen-like tools for drawing. The findings are used to identify tactile cues that could be implemented in a computer haptic environment with the support of the current technology. The identified cues are used as design requirements for developing a haptic drawing prototype, called HapticDraw, which is described in Chapter 6. The description of this implementation presented in Chapter 6 also involves a formative evaluation and redesign of the prototype. Two types of interface designs for HapticDraw have been implemented following from the theoretical understanding presented in Chapter 5. Chapter 7 presents a main comparison study to evaluate the prototype. Among the objectives of the study are to determine whether variation in force feedback is preferred in a drawing application, and which of the two design interfaces, as implemented in Chapter 6, users prefer to interact with and the reason for such a choice.

Chapter 8 draws a conclusion for this research thesis and provides suggestions for future work.

Chapter 2 User Experience of Haptics

2.1 *Introduction*

The aim of this chapter is to provide a background understanding of user experience in relation to haptic interactions that could assist in the development of a haptic interface design. This is motivated from the fact that user preference is a factor that influences acceptance of a haptic interface as noted in Chapter 1. This chapter provides the first part of the literature review that aims to establish substantive knowledge towards answering the research questions in this thesis.

This chapter examines how knowledge obtained from user experience of haptic sensations in the real physical world has been applied in haptic interface design studies. This examination leads to understanding the context or situation in which the user haptic experience and perception is to be employed. In the case of this research project, the focus is narrowed down to a drawing and sketching domain. An overview of drawing based on user experience in the real world interactions is then presented. This chapter emphasises the importance of understanding user experience in order to design haptic interfaces that are acceptable to users.

2.2 *User Experience of Haptic Sensations*

This section reviews empirical work that discovers the underlying nature of haptic interactions, before designing a computer system. The way to gather the characteristics of such interactions is mainly through an understanding of the real world situation. These characteristics reflect behaviour from the human haptic system and the physical simulation, and user experience and perception.

2.2.1 Human Haptic System and Physical Simulation

The sense of touch is a principal contributor to many high level integrated perceptual functions (MacLean, 2000). Information obtained from this sensory system helps in an assessment of an object's dynamic and material properties, verification of engagement and completion, continuous monitoring of ongoing activity and gradual completion of a specific task, building mental models for invisible parts of a system, and judgment of other people.

Like any graphical user interfaces, when representing haptic information in a computer system, elements ranging from the users to the surrounding environment involved need to be understood. MacLean (1999; 2000) emphasises the relationship between these various elements by providing a set of taxonomies of physical interaction which cover special qualities of touch, and why, how and what kinds of things people touch. She proposes a four-layered model of multi-sensory interaction with an environment illustrated in Figure 2-1.

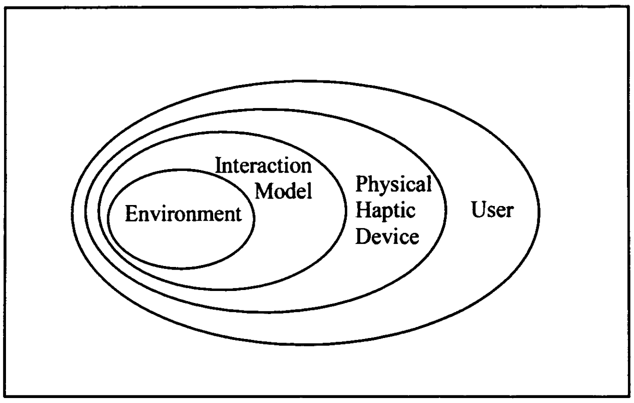


FIGURE 2-1: A MODEL OF MULTI-SENSORY INTERACTION

The model in Figure 2-1 is aiming towards providing designers with some possible attributes that a "good" haptic design should exhibit. In the context of this research project, the "user" element is associated with the user experience that we possess when interacting using an intended device.

To understand the relationship between user experience and the "environment" element, knowledge obtained from the psychophysics field is essential. Interface designers use findings on how people perceive and manipulate active and passive exploration of touch (Klatzky and Lederman, 2002) in the real world to simulate haptic behaviour for interactions. Haptic texture is an area, which is a result of active exploration. In relation to haptic texture, Hughes and Jansson (1994), and Jansson and Hughes (2000) discussed the concept of passive and active touch in order to better understand the haptic domain. Passive touch refers to cutaneous sensitivity and is associated with receiving tactile information. On the other hand, active touch is considered as a movement in texture perception by touch. It is used to investigate objects and their properties and to interact with our environment. The information expected from this type of touch involves both cutaneous and kinaesthetic feedback. According to Jansson and Hughes (2000), information on both types of touch is needed for perceptual accuracy when dealing with complex situations. The understanding of this haptic information is necessary in order to create a better haptic interface design.

From the multi-layered model in Figure 2-1, in order to develop a haptic virtual environment, the emphasis on understanding the (physical) interaction modelling is as important as the technical capability of the device to be used for an interaction. Burdea (2000) points out that the elements required in such interaction behaviour include user interaction that is primarily through collision detection, object response such as surface deformation, hard contact simulation and motion constraints. He highlights that surface texture is another important aspect of physical modelling that allows the virtual objects to be characterised such as smooth, rough, and slippery. In the modelling, the computation of the contact forces present during object deformation and the application of these forces on the user enable a realistic simulation to happen. The way we interpret this haptic feedback to obtain meaningful information relies heavily on our perception.

2.2.2 User Haptic Perception and Experience

An understanding of how we perceive haptic feedback is fundamental before designing an interface. Most of the haptic perception depends on our understanding and interpretation that result from active exploration (Lederman and Klatzky, 1999), which is a form of gesture. We usually describe the things we feel in three different ways: cognitive, perceptual and physical (Minsky, 1995). The cognitive descriptions comprise elements of semantics, e.g., "pebbles"; metaphorical, e.g., "like corduroy"; functional, e.g., "like driving on a road"; and affective, e.g., pleasant. The perceptual description is more towards the haptic properties of the sensation such as "rough", "bumpy", "slippery" and, "sharp". On the other hand, physical descriptions provide examples such as "1/4 inch high bump" or "grooves ½ inch apart". The broad concept of human touch and the way we describe the sensation felt may be able to assist in discovering haptic feedback suitable for interface designs.

The way we perceive haptic information in the real world could be used to inform design requirements. This is justified from the fact that haptic technology, such as PHANToM (SensAble Technologies, 2004), could be used to demonstrate how our perception can be deceived, resulting in users perceiving the haptic sensation expected (Bordegoni et al, 2001). The device provides a single-point contact of information during a haptic exploration on an object's surface. Our ability to distinguish these point-like events and mentally integrate in time the continuity of a sequential signal enables us to feel the haptic sensation when touching the surface. Ramloll et al (2000) provide a similar justification on the capability of the PHANToM in terms of creating tactile sensations for virtual objects. The perception of such sensation is also strengthened by the user's previous experience interacting in their daily life. Should the haptic properties such as "rough", "bumpy", "slippery" and, "sharp" be included in the design, users are able to perceive such intended sensations upon performing active exploration on a surface of an object.

Based on human haptic perception and haptic exploration in the real world, many studies have been carried out that involve the haptic sensations. For example, Klatzky et al (1993), Lederman and Klatzky (1999), and Klatzky and Lederman (2002) focus on surface roughness and note that it is the most important property (attribute) of haptic texture. According to Lederman and Klatzky (1999), the primary physical determinants for perception of surface roughness are: abrasive-surface, controlled linear gratings and 2-D raised dot patterns. Lederman and Hamilton (2002) applied this attribute extensively in a Canadian banknote case study. The roughness perception has been tested which resulted in the acceptance of one of the raised texture-features by the Bank of Canada. There are other attributes of surface properties such as slipperiness, tackiness (Lederman and Klatzky, 1999; Klatzky and Lederman, 2002), hardness, temperature and weight (Klatzky et al, 1993), which have been noted but were not explored.

The importance of haptic features in an application has also been highlighted in an art-related project, called Tacitus, reported in Shillito et al (2001). The work follows as closely as possible the way the real world operates and creates a generic virtual environment that could be applied to various similar applications within the same domain. The preliminary study in the project was to investigate the use of a multimodal virtual environment with regards to the creative process. One of the main findings suggested that there is a need to imitate the traditional applied artists' workspaces, particularly in the provision of visual and haptic cues. In an example of glass blowing, the properties of tools and materials used for the process should be included in a computer environment. In this case, temperature, viscosity and adhesive properties are among the haptic features that could be imitated. If haptic cues are important as Shilllito et al suggest, what essential knowledge is required that could lead to identification of these cues especially for a drawing environment? One relevant area to understand is the nature of the tools and the haptic features supported with regard to the environment in question.

2.3 "Everydayness" Experience and Phenomenology of Tools

Designing interfaces that incorporates users' tactile experiences has indirectly made the phenomenology concept (Sion, 2003) useful to be considered as part of a design rationale. In general, this concept is about activity of interpretation that is not limited to a particular situation, but encompasses our every day life. This "everydayness" (Heidegger, 1962) experience helps one to interpret and understand a particular phenomenon (object). Winograd and Flores (1986) explained the activity of interpretation as a circle of things that we understand with what we have already known. In brief, things that we understand are based on our previous knowledge and those that we knew resulted from our ability to understand a similar context. As the cycle evolves, we tend to learn more from our interactions, perceptions and understanding of the objects that we encounter in our daily life. From this process, we will either confirm our interpretation of a particular object based on our previous experience or alter our beliefs. The idea of encouraging the process of recurring interpretation through "everydayness" experience should be cultivated in a design since it can promote active learning in a computer environment. A careful consideration in deploying people's every day experience should encompass the human and technological aspects of human-computer interactions.

For the human aspect, such deployment could be seen in the success stories of interface metaphors used in many computer designs, for instance the classic example of a desktop metaphor. The realisation towards designing an interface that resembles the physical real world and familiar to users has made the metaphors highly accepted. Pictorial representations of typical objects on the top of an office desk have been transferred and organised on a desktop of a computer screen. This familiarity provides a basis of understanding for the users to interact with the icons easily.

In terms of the technological aspect, the influence of the everydayness experience can be found in the choice of input devices for interactions. This chosen device is required in order to communicate with the computer system effectively and promote a natural interaction as closely as possible. Even though the selection is usually dependent on the kinds of environment in which the device can be beneficial, Preece et al (1994) urge that an important criterion is the one that matches the physiological and psychological characteristics of the users, their training and expertise. This reasoning corresponds to a good design practice in which the technology should be employed to suit the users' needs rather than the other way round.

From the phenomenology of a user's perspectives, a suitable input device could be profoundly meaningful when utilised through their own contextual practice. For example, a drawing activity requires a device that supports continuous motion whereas choosing a menu selection needs a tool that allows discrete movement. The tool or device that is really needed for a specific work context is the one that will not hinder users from performing their tasks or activities during an interaction. Users should only notice the existence of the tool used when something goes wrong with the interaction. This idea corresponds to Heidegger's concept of "breaking down" whereby objects (tools) and their properties (affordances) are considered as not connected with one another. When the objects are being utilised in an environment, the relationship with their properties may go unnoticed if a flowing process of interaction happens. However, this relationship becomes apparent in the event of "breaking down" in which the objects become present-at-hand. From the example presented, and the justification using the "breaking down" concept, it could be implied that having no or very minimal "breakdown" occurrence would be ideal for a drawing interaction as this would not interrupt the users' concentration in doing their task. This situation should be maintained throughout an interaction using a haptic drawing application. It could be made possible through choosing an appropriate haptic device.

With regard to examining the tools used for a specific work context, Shillito et al (2001) investigated the implements employed in art-related work and reported that a wide variety of hand tools were utilised by the artists. The general work pattern reveals that a single tool is often used for a number of different purposes and thus this tool is very flexible in the hands of the artists. According to Shillito et al, the relatively low use of computers within the artist community is due to the rigidity of the current input device for interaction. This limitation becomes a barrier to the artists' creative process. This prompts the question: how can such versatility in the feature of a tool obtained from the real world possibly be replicated in a computer environment? It is a challenge for a designer to find a suitable haptic device for an intended interaction in order to match the capabilities of the device with the task in context. With the chosen device, a way should be sought to make the force feedback generated emulating the tactile sensation of various tools.

To obtain a tool which matches the physiological requirement may not be adequate for the system if the tool is not capable of supporting the functionalities expected by the users. A balance between physiology and functionality is required so that users could feel the natural interaction in terms of physically using the device as well as the feedback received from an interaction. Scali et al (2002) highlighted that artists would only use computers when these technologies offer advantages over traditional tools and have features relevant to their activities. With regards to haptic interface designs, it is important to have a suitable device(s) that could provide sufficient and appropriate system feedback (Norman, 1986) in order to get good feedback of the tactile sensation felt. If this feedback fails to exist the issue of artists not using computers for their work may still prevail. Such a situation may not be to the advantage of artists as haptic interfaces have been claimed to support creative activities. Given the infancy of computer haptic interfaces as a research area, we may have to compromise with the limitation of a particular device used. However, it is still a challenge to the designers to ensure that the existing capabilities of the technology are fully exploited. A careful design, for which feedback produced is based on users experience and perception, may be able to gain users' acceptance in terms of the haptic sensation that matches the real world situation.

Understanding how user experience using a tool for interaction in daily life provides an insight into designing an interface. Rosand (2002) studied the relationship between drawing and writing from the great masters such as Leonardo and Vasari. He noted that writing is comparable to drawing. Both practices share the same instrument e.g. pen and such activities are acknowledged by their similar manual acts. An experience, especially on the tactile sensation, when using a pen-like tool could be appreciated and better understood by examining the phenomenology of drawing and writing.

Chandler's (1992) work used some key features, which include directness of inscription, uniformity of script, speed and linearity, to understand people's experience using pen-like tools for writing. He described that the directness of inscription refers to a suspension in time and indirection in space. In this case, a pen or pencil has a direct inscription, in which some writers considered this tool as an immediate extension of their fingers. An example of spatial indirection can be seen in the case of the typewriter whereas the word processor involves both spatial indirection and temporally suspended inscription. In this case the word processor has the least direct inscription. When writing using a pencil (or pen) on a paper, the writers feel that they are touching the words. They believe that the handwritten text is at the tips of the writer's fingers. This means to write with a pen or pencil is to touch one's text. Consciousness is focused at the point of the pen. This leads towards understanding the experience of drawing especially when using a pen tool.

2.4 Experience of Drawing

This section examines the nature of activities involved in a drawing process. The idea is to provide an understanding of the process so that relevant elements in the drawing activities could be extracted and considered for a haptic interface design.

2.4.1 Drawing Act – The Importance of Pen-like Tools

Traditionally, people draw an object by using tools such as pen, pencil and brush. The role of these pen-like tools in a drawing process is found in a statement by Sanderson (1658) who said, "The most excellent use of the *Penn* and *Pensil*, is illustrated by the admirable Art of *Drawing*, and *Painting*; and perfectly defined, to be the *Imitation of the Surface of Nature*, in *Proportion and Colour*". Sanderson urged artists to fully utilise their visual sense when drawing and to use the tools for perfection, ease and speed. Hayes (1978) described a pencil as a convenient and expressive means of evolving a composition and of recording visual information for translation into another medium later on. The importance of this pen-like tool has also been indirectly highlighted in Rosand (2002). Rosand noted that there are some visible traces of pen marks in some of Raphael's oil painting. These pen marks are used to establish a basic design for the artwork.

Matisse's statement which complimented the usefulness of a pair of scissors for his artwork on paper cutouts was highlighted in Guichard~Meili's (1984) book. Matisse said, *"A pair of scissors is a marvellous instrument. And the paper I use for my cutouts is magnificent.*

Just feel it! ... It took a lot of research and many experiments to find it. I can become totally absorbed in working on this paper with scissors... " Despite the fact that scissors do not have the physical characteristics (i.e. in terms of shapes) of a pen-like tool, Matisse's statement has raised an interesting example of people's experience when using tools for artwork.

There is a pattern showing that in a more recent work, researchers have attempted to examine the physical characteristics of pen-like tools and incorporate their findings to a computer environment. This is seen in studies carried out by Sousa and Buchanan (2000) and Amant and Horton (2002), to name a few. Sousa and Buchanan chose pencil as a tool in their work because it is a flexible medium. According to them, a pencil can provide a great variety of styles in terms of producing different line qualities, supporting hand gestures and building tones. However, their work does not include the tactile perception when using the pencil. The study is more focused on presenting models for graphite pencil and other drawing materials such as paper and kneaded eraser to produce realistic looking pencil marks, textures and tones.

Like Sousa and Buchanan, Amant and Horton (2002) studied the conceptual foundations of tools and their use in close detail. They claimed that a deeper examination of physical tools used in the real environments such as a carpenter's workbench and a chef's kitchen can improve the design of interactive software. From this investigation, they identified some of the properties of physical tools, which are not commonly found in the present software. The abstract classes to describe these properties are: effective tools – tools that produce a persistent effect on materials and environments; instruments – tools that provide information about materials or the environment; constraining tools – tools that constrain or stabilise materials or the environment for the further application of effective tools. These properties are used to formulate a taxonomy, which involves characterising tools as objects. Their approach in developing this taxonomy has taken into account the relationship between a tool and its environment. Here, Amant and Horton stressed that the applicability of a tool is determined by its ecological properties. For example, any sufficiently solid and heavy object could be used as a substitute to a hammer whenever this tool is not at hand. This leads to other tool properties, which include the facts that tool use can be opportunistic; tools provide rich cues about their appropriate use; and tool use involves establishing and exploiting constraints between the user and the tool, the user and the environment, and the tool and the environment. The outcome of this taxonomy is reflected in their drawing application called HabilisDraw. This prototype is intended for exploring the use of software-based tools in an interactive system. There are six types of tools available: rulers, compasses, pens, ink wells, pushpins, and lenses. Amant and Horton evaluated the prototype and reported that users found the tools easy to use and enjoyable.

2.4.2 Pen-like Tool in Use

A drawing act involves the elements of subject and object; perception and presentation; eye and mind; and hand and body. We are able to know how others (i.e. artists) perceived an object from their drawings (representations). Rosand (2002) reported that Leonardo believes that an artist 'sees' the world with his hands as well as eyes. When one is drawing, the tracing hand directly records the movements of the body. The line is a direct record of an artist's gesture. Basically, this line involves the kinaesthetic of the act of drawing and writing. There are several properties that are associated with these acts such as its (line) qualities of direction, velocity, weight, rhythm, pace and inflection. When their meanings are interpreted, these properties could convey the feeling of the artist during the process of drawing. Beneath this visual representation lies a powerful tactile feeling that influences the artist's mind during the drawing process. As highlighted in Section 2.2.1, such drawing acts involve a movement in texture perception of touch in which the tactile properties for example hardness, slipperiness and tackiness could be invoked and felt.

The implement used for drawing could be seen as a medium in which the artist's mind could be transferred on to the (drawing) surface. The design of interactions in a drawing application should replicate the physical behaviour of the real world tool. Shillito et al (2001) noted that based upon user (artist) requirements, the virtual objects being manipulated and the tools used have to be operating in a similar way to the real world and the mode of working should feel the same. In other words, the hand gestures and haptic elements need to be supported when drawing. According to Wing et al (1996) the haptic elements involved in a drawing process are: the viscous forces, the stiffness, the inertia, positions and orientation data, vibrations, and oscillations. An illustration of a hand movement during such a process is presented in Figure 2-2.

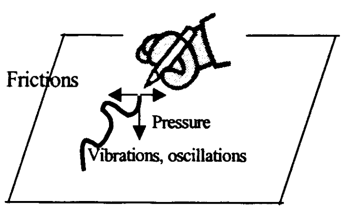


FIGURE 2-2: A HAND MOVEMENT DURING DRAWING

In Figure 2-2, the friction coefficient is dependent on the paper or material used. There is a correlation between the pressure variations, the line width, the tool or pen, and the paper used. The user's hand movement generates vibrations or oscillations in an interaction. Reflecting from the information in this figure, the haptic sensation needs to be felt when the pressure and friction occur in a drawing interaction. In Section 2.2.2, the haptic effect for interactions such as roughness, slipperiness, and tackiness are addressed but the questions leading to it are: how relevant these cues are in a drawing interaction? Do they represent a "complete" set of cues in a drawing domain? The fact that the role of haptics is very context dependent as described in Section 1.1, indicates that haptic features in one particular domain may not be useful to another. In such a case, there is a need to find the haptic cues for a drawing domain. The issues pertaining to the haptic feedback leads to many others, which include: would users of a computer-drawing environment prefer to have a haptic sensation that mimics reality? Or would they want an unconventional option whereby the haptic feedback felt from a drawing interaction does not represent any specific tactile sensations as in the real world? These are some issues that will be addressed in this research project.

2.5 Chapter Summary

This chapter has established a foundation to understand user experience in perceiving haptic sensation and drawing in the real world. The intention is to exploit knowledge from this understanding to design haptic interfaces acceptable to the users.

In general, haptic modality helps us to receive information about an object's compliance, texture, shape and heat conductive qualities. The way we interpret this information relies heavily on our perception. The process of interpretation follows the circle of what we perceive with what we have already known. Upon our active exploration on a surface of an object, we are able to perceive the haptic feedback intended for a simulation. Such perception is usually based on our understanding and experience of similar situations interacting in the real world. This situation signals that users' experience in haptic perception could be used as part of a design requirement. The fact that such perception could be judged upon active surface exploration, also provides a hint to designers on how to create a haptic interface. The basic understanding on how we perceive haptic feedback presented in this chapter offers relevant knowledge when designing a haptic interface.

This chapter has also introduced some concepts in phenomenology such as the "everydayness" experience and existential phenomenology. The motive is to provide a foundation in terms of design rationale when justifying matters pertaining to user haptic experience. The "everydayness" experience can be used to influence the choice of haptic devices for interaction. Also, knowledge in existential phenomenology can help in understanding better users' experience when using pen-like tools for drawing. When applying this knowledge to the way we perceive a haptic sensation, an interaction with fewer occurrences of 'breakdowns' could be perceived as desirable since it does not interrupt users' engagement.

This chapter indicates that presenting haptic information in an interface design for a drawing application could pose many challenges such as finding suitable haptic feedback for a drawing application. The knowledge obtained from understanding user experience and perception will help address issues highlighted in this chapter.

Chapter 3 Haptic Cues for Supporting Interaction Design in the Drawing Domain

3.1 Introduction

The aim of this chapter is to present a study to identify haptic features for the drawing domain. It addresses the questions of the type of haptic sensations that users perceive in a drawing process. This is motivated by the research findings in Chapter 2 which has highlighted that knowledge received from understanding user experience in perceiving haptic sensation and drawing environment in the real world could be used to design haptic interfaces acceptable to the users. This chapter provides the first part of the practical work in this research project that aims to address the questions presented in Section 1.2 as follows:
Question 1: What are the haptic features involved in a drawing domain?
Question 2: What are the haptic features suitable for a drawing application?

This chapter describes how the exploratory study was conducted. It suggests an approach that considers how to capture a relevant set of haptic cues as design requirements for a computer-drawing application. The approach involves utilisation of users' experience and perception in understanding the tactile experience when drawing in the real world. The chapter progresses by extracting the study findings and justifying the appropriateness of the potential cues suitable for a computer drawing interface to be developed in this research project. A refinement of these cues is presented so that they could be easily integrated in a development process. The chapter ends with a summary section to highlight the important findings from the practical investigation presented.

3.2 Study Approach

This section presents an argument based on literature regarding conducting art-related research in seeking and understanding user haptic experience. The intention is to determine and justify the study approach to be taken in the study. The choice of the study approach is important in order to exploit the knowledge of user haptic experience and perception in this research project.

In understanding user haptic experience, Scali et al (2002) and Shillito et al (2003) attempted to move away from focusing towards the end product of art-related work on to the process of the creative work, instead. They argued that during the early conceptualising stage of the design development, the mental processes in terms of conceptualising and externalising a particular idea are similar amongst the different domains. In such a case, it is vital to generalise the activities in this stage because the experience involved and lessons learnt in the design may be transferable to other domains. Scali et al also raised a question about how haptic interactions in computers can be exploited in a manner complementary to that of reality. The challenge is that generalisation is difficult to make because most study findings reported are task specific and partially dependent on technology. They suggest that investigating the haptic component of the interface within its bigger domain is a possible approach. For example, in order to integrate a haptic device into a CAD system, the relevant framework of spatial-input interfaces for 3D-shape conceptual design should be looked into. The argument implies that a qualitative approach and broadening the scope to the domain of study in question would be more appropriate when investigating user subjective experience in a particular process of interaction. This has influenced the study approach presented in this chapter specifically and the rest of this research project, in general.

3.3 Identification of Haptic Cues in the Real World Interaction

The objective of this section is to present a study that investigates the haptic sensations that artists recognise in a drawing interaction. It describes how an exploratory study is carried out and how the data analysis is performed in order to achieve the intended goal. This part of the research has been presented and published as a short paper in the British HCI2004 conference proceedings. Appendix 3-1 provides a copy of this reported work.

3.3.1 Motivations

This study is designed to identify tactile features that are significant in the drawing domain. The main objective of the study is to compile a structured vocabulary of users' experience when using drawing tools, focusing on the haptic properties and features of the drawing domain. Despite the graphical aspect not being a focus in this research, the visual cues related to the tactile sensation while drawing or sketching are still examined. This is to assist in developing the design requirement and possible suggestions for future investigation.

3.3.2 Participants

Twenty-one traditional artists took part in the study (thirteen females and eight males). Nineteen of these artists were recruited among the arts students from the Slade School of Fine Art at University College London. Fifteen of them were undergraduate students while the other four were postgraduate scholars. All these students responded to an advertisement pertaining to the evaluation study posted at the school notice board. The rest of the participants who took part were practicing artists who paint for a living. Members of staff from the Computer Science Department introduced these artists to the researcher. With regard to the drawing domain under study, this target group can be considered as 'experts' in the field. All participants were paid upon completion of the study.

3.3.3 Pre-Study Preparation

Before starting with the evaluation, all artists were briefed on the objectives of the study. (See Appendix 3-2 for a sample document). They were asked to sign a consent form to indicate that they understood the purpose of the study and their participation was fully voluntary. (See Appendix 3-3 for a sample Consent Form used).

It should be noted that a pilot study using six evaluators involving staff from the Computer Science and Psychology departments was conducted prior to the actual study to ensure that the study design was appropriate.

3.3.4 Study Task

All the artists were interviewed and the conversations were audio recorded. No video recording to capture the artists' drawing interactions was involved. During the interviews, the artists were given a collection of 9 pen-like tools consisting of 4 pens, 3 pencils, a crayon and charcoal to work with. These drawing implements were chosen based on their physical features such as the shape of the shaft (e.g. big, small, tall, and short) and the tip of the pen-like tools (e.g. thin, and wide), and the weight (e.g. heavy and light). Such selection was intended to cover as much variation of pen-like tools as possible. These pen-like tools were labelled as 'PN1', 'PN2', 'PN3', 'PN4', 'PCL5', 'PCL6', 'PCL7', 'CR8' and 'CHAR', respectively. Two types of drawing paper were used: A4 paper to represent a smooth surface and watercolour drawing paper for its rough counterpart. Details of these tools are presented in Appendix 3-4 for referencing purposes in this thesis. These drawing implements were also chosen to represent the tools that artists usually used in their daily activities. This corresponds to the "everydayness" concept presented in Section 2.3 when choosing appropriate tool for intended users.

In this study, the artists were asked to freely describe the tactile sensation and the visual appearance of each tool while holding it in their hands. Using the tool, they were asked to do free drawing or writing on the two different types of textured paper. The task was designed in this manner so as not to limit the artists' creativity and also an attempt to generalise the results in terms of the tactile sensation felt for a drawing domain. This is in line with Scali et al (2002) and Shillito et al (2003) on making generalisations from study findings presented in Section 3.2. During the artists' drawing interactions in this study, they were asked to talk out loud about the tactile sensation they experienced and the appearance of the marks produced when they used each tool and paper. They were also encouraged to talk about any similar experiences using drawing tools in their daily work. Throughout the study, all artists were allowed to speak freely of their experience interacting with the drawing implements.

3.3.5 Data Treatment and Analysis

The recorded conversations were transcribed verbatim by the researcher to obtain 21 sets of data, each of which contains information on an individual artist's experience using the tools. From each set, the vocabulary that was used by the artist was identified. In this exercise, the way people describe tactile sensation as reported in Minsky (1995) and discussed in Section 2.2.2 was observed. The vocabularies were examined to identify the terms used by each artist across all the 9 pen-like tools and two paper types. For example, the terminologies used by Artist 1 to describe the tactile sensation when interacting with the 9 pen-tools and 2 paper types included: "*resisting*", and "*quite smooth*" (PN2 on smooth paper); "*quite smooth*" (PN1 on smooth paper); "*does not slide*" (PCL5 on smooth paper); "*vague vibration*" (PCL5 on rough paper); "*smooth*" (PN3 on smooth paper); "*flaky*" (CR8 on rough paper); "*squishy*" (CHAR on smooth paper). The same procedure was replicated to the rest of the data from all other artists who took part in the study.

From the 21 sets of data, any similar terms were grouped under the same category, regardless of the pen-like tools and paper type combinations used. In this case, any descriptions of a particular tactile sensation that involve the same terminology or similar expressions that is referring to the same concept are classified together. To demonstrate a simple example, the terms such as "*quite smooth*" (PN2 on smooth paper), "*quite smooth*" (PN1 on smooth paper), and "*smooth*" (PN3 on smooth paper), could be combined under a group heading called "smooth". (See Appendix 3-5 for a sample of detailed categorisation involved in this exercise).

The groups obtained were further classified into a higher level based on the actions made by the artists during the study, so as to determine at which stage of interactions a particular haptic cue should be applied into an interface design. For example, the haptic cues that occur when an artist was examining the pen-like tool, drawing on a paper surface and any other medium of interactions involved were identified. These stages correspond to the tasks given to the artists as described in Section 5.2.4.

To check consistency of the terms used by the artists when describing each tool, an orthogonal data analysis was performed. In this, the transcribed data was transformed into 9 different sets based on the tools used in the study. The terminologies used by all the 21 artists to describe the tactile sensations when using each tool were identified. For example, among the terms used to describe the tactile sensation of a crayon on smooth paper are: "*waxy*" (Artists 2, 11, 15), "*sticky*" (Artists 3, 6), "*soft*" (Artists 5, 11, 14, 15), "*so soft*" (Artist 20), "*smooth*" (Artists 5, 7, 8, 10), "*very smooth*" (Artists 17, 19), "*silky*" (Artists 7, 17), "*velvety*" (Artist 10), "*squishy*" (Artist 13), "*flowy*" (Artist 15), "*creamy*" (Artist 16), "*glides*" (Artists 16, 19). The same process was replicated for the rest of the pen-tools used in the study.

These terms were cross-examined to assess consistency among artists in describing the tactile sensations of each pen-like tool and paper type combination. No major inconsistencies were found. A similar approach to analysing the haptic feedback perceived was taken for identifying the related visual cues.

3.3.6 Results

The data analysis has resulted in two inter-related sets of information on the haptic and visual elements. In this study, both sets of elements were classified and presented based on the interactions involved in the drawing domain. For this data analysis, all the study findings are presented but later only those pertaining to haptics elements for pen-like tool and paper are further considered.

Haptic Elements for Drawing Domain

The properties and features of the haptic cues found in this study are presented in Table 3-1. Three main types of interactions are identified, based on the logical pattern of the actions made by the artists. This pattern is supported by Klatzky et al (1993), who present their concepts of exploration procedures using the hand, and Klatzky and Lederman's (2002) work on feeling textures through a probe. The 'hand and tool' interaction occurred when the artists described the tactile sensation while holding the tool. The 'tool and surface' interaction occurred when the tool touched the surface of the paper, as the artists were drawing or writing, and the 'hand and surface' was when the artists used their own fingers to smudge the mark on the paper. These types of interactions correspond to the study analysis in classifying the groups of haptic features in a higher-level manner as described in Section 3.2.5. The three types of haptic interactions are important because they could provide a basis to classify the specific haptic features in a drawing interaction.

TABLE 3-1: PROPERTIES & FEATURES OF A HAPTIC DRAWING DOMAIN

Type of Interactions	Actions	Properties	Features	
Hand & Tool	Hold	Surface texture (tool)	Smooth	Bumpy
			Soft	Hard
			Slippery	Plasticky
			Rubbery	Metallic
		Temperature	Cold	Warm
		Weight	Light	Heavy
		Shape	Short	Long
			Thin	Thick
			Round	Sided
		Grip	Slipping	Not slipping
Tool & Surface	Press	Surface texture (tool)	Soft	Hard
			Sticky	Dry
	Push	Surface texture (paper)	Smooth	Rough
		Friction (tool & paper)	Soft	Hard
			Sticky	Dry
			Waxy	Powdery
			Smooth	Glide
			Flows	Silky
			Velvety	Creamy
			Stiff	Sharp/ scratchy
			Bumpy/ rough	
Hand & Surface	Smudge	Surface texture (paper)	Soft	Rough

From Table 3-1, the action "hold", relates to the first type of interaction in which the haptic exploration involves the hand and the tool. When holding the tool, the haptic properties that could be assessed were the *surface texture*, *temperature*, *weight*, *shape*, and *grip* of the tool. These properties which are associated to the tool used were noted by the artists during the study. For the *surface texture* property, the artists commented on the smoothness, hardness, slipperiness and material of the tool. As an example, when commenting on PN1, five artists said that the *surface texture* was bumpy because of the indented grip. Four artists said that PN1 is made of metal so it is hard and slippery. The properties of the *surface texture* of the tool correspond to the exploration procedures, 'lateral motion' and 'pressure' as noted by Klatzky et al.

The artists noted the *temperature* of the tool in terms of its coldness, and the *weight* in terms of its heaviness. For example, seven artists said that PN1 was cold and sixteen said that it was heavy. The properties of *temperature* and *weight* correspond to Klatzky et al's 'static contact' and 'unsupported holding' exploration procedures, respectively. The *shape* of the tool was noted in terms of its length, width and roundedness and the *grip* of its slipperiness. Three artists commented on the size of PN1 as a thick implement. The information about the *shape* and *grip* is obtained when the artists did the 'enclosure' and 'contour following' exploration procedures as noted by Klatzky et al.

The second type of interaction involves two main actions made by the artists: "press" and "push". In this analysis the action "press" is considered as a passive touch (Klatzky and Lederman, 2002). This action correlates to Klatzky and Lederman's exploration procedures on the 'pressure'. The action occurred immediately after the tool touched the paper. From the evaluation study, the artist could feel the *surface texture* property of the tool which they described as 'soft', 'hard', 'sticky' or 'dry'. These sensations were also felt and expressed by when most of the artists voluntarily and spontaneously made 'dotted patterns' on the paper.

In contrast to the action "press", "push" involved active haptic exploration (Klatzky and Lederman, 2002). This action covers the 'lateral motion' and 'pressure' type of exploration procedures. The artists applied force and made a mark on the paper. The study findings revealed that the "push" action provided information about the *surface texture* of the paper. It also produced a *friction* property between the tool and the paper, resulting in features including all those noted under the "press" action and also other cues such as 'smooth', 'glide', 'stiff', and 'sharp/scratchy' (see Table 3-1 for a full list). The *surface texture* is an important element to take note of in this study as this property affects every action made in the drawing interaction. It should also be noted that the haptic features shown in this table are presented in no particular order of sequence.

The third type of interaction involved the artists smudging the mark with their fingers ("tool"). This involves direct haptic exploration using hands. Based on the study findings, the information obtained includes properties of the object's texture and information on the pressure applied. The artists could feel the properties of the *surface texture* of the paper while interacting with the "tool". The exploration procedures involved in this interaction are the 'lateral motion' and 'pressure'. The 'soft' and 'rough' features obtained for this interaction are referring to the cues of the *surface texture (paper)*.

Visual Elements for the Drawing Domain

The haptic properties for the drawing domain are closely related to the visual cues perceived. The tactile cues may correlate to the visual appearance of the mark; for example, a 'stiff' sensation during drawing or writing may produce a 'shaky' or 'agitated' line. The properties and features of the visual domain are shown in Table 3-2.

TABLE 3-2: PROPERTIES & FEATURES OF A VISUAL DRAWING DOMAIN

Type of Interaction	Object	Properties	Features
Pre - Interaction	Nib	Shape	Sharp/ pointed, Blunt, Thin, Wide
	Shaft	Shape	Thin, Chunky, Round, Angular
		Surface texture	Smooth, 'Blobs'
		Appearance	Colour, Shiny, Material
	Paper	Surface texture	Smooth, Textured, Glazed
		Thickness	Thin, Thick
Post – Interaction	Line	Pressure Mark	Clean/ Precise/ Definite, Uniform/ continuous, Delicate, Soft, Light, Distorted, Even, Jagged, Shaky/ agitated, Broken, Fuzzy/ blurry, Uneven, Blotchy/ messy, Smudgy, Harsh, Strong, Thin/ small, Thick/ heavy, Black (ink), Blue (ink), Dark, Bold, Black, Bumpy, Rough, Grainy, Dry, Watery, Shiny

In analysing the visual effect, two different stages of interactions that involve visual sense were established. As shown in Table 3-2, the first stage is called the "pre-interaction". This occurs before the drawing or writing activities. The appearance of the nib and shaft of the tools and the surface of the paper were observed. The nib has a property *shape* which refers to the sharpness and thickness of the tip. The observable shape of the nib is expected by the artists to allow them to anticipate the different types of marks that will be created when friction is produced during drawing or writing.

The shaft of the tool has visual properties pertaining to its *shape*, *surface texture* and *appearance*. The *shape* of the shaft includes its thickness and roundedness, the *surface texture* its smoothness, and the *appearance* its colour, material and shininess. The visual shape of the shaft – for example, 'chunky' – is expected to correlate to the (felt) weight of the tool.

The appearance of the paper has properties of *surface texture* and *thickness*. The *surface texture* is said to be 'smooth', 'textured' or 'glazed', while the *thickness* could be either 'thin' or 'thick'. These visual features are expected to influence the haptic *surface texture* and the tactile sensation felt from the *friction* that occurs when the action "push" takes place during drawing or writing.

The second stage is called "post-interaction". This is when the writing and drawing activities have been performed. At this stage the appearance of the line is observed. The line is examined for its *pressure mark* properties. The features associated with this property include 'uniform' or 'continuous', 'delicate', and 'distorted' (see Table 3-2 for a full list). These features are expected to be the result of the friction produced during the interaction between pen-like tool and paper. For example, the feature 'smooth' of property *friction* in Table 3-1 may produce a 'uniform/continuous' line in Table 3-2. Similarly, the 'bumpy/rough' feature may produce a 'distorted' line. Like the approach used in presenting the haptic cues in Table 3-1, the visual features shown in this table are also presented randomly i.e. no particular sequence.

3.4 Identification of Potential Haptic Cues for Simulation

This section aims to examine the haptic cues obtained from Section 3.3 so that they can be used as part of design requirements in a computer-drawing environment. It involves identifying the potential cues suitable for a computer environment and how they can possibly be presented in a simple manner in order to suit the development purposes.

In Section 3.2, of the three types of interaction in the domain of haptic cues, only the "tool & surface" is suitable to be integrated in the computer environment. This type of interaction can be interpreted as a representation of a user interacting with a computer interface (drawing application) mediated by a haptic input device. Table 3-3 extracts the tactile cues information of the "tool & surface" type of interaction from Table 3-1. These cues are relevant to the computer environment.

TABLE 3-3: 'CHOSEN' TACTILE CUES FOR COMPUTER ENVIRONMENT

Type of Interactions	Actions	Properties	Features	
Tool & Surface	Press	Surface texture (tool)	Soft Sticky	Hard Dry
	Push	Surface texture (paper)	Smooth	Rough
		Friction	Soft Sticky Waxy Smooth Flows Velvety Stiff	Hard Dry Powdery Glide Silky Creamy Sharp/ scratchy
			Bumpy/ rough	

The corresponding visual features for the haptic information presented in Table 3-3 were shown in Table 3-4. This is extracted from Table 3-2.

TABLE 3-4: 'CHOSEN' VISUAL CUES FOR COMPUTER ENVIRONMENT

Type of Interaction	Object	Properties	Features
Post – Interaction	Line	Pressure Mark	Clean/ Precise/ Definite Uniform/ continuous Delicate Soft Light Distorted Even Jagged Shaky/ agitated Broken Fuzzy/ blurry Uneven Blotchy/ messy Smudgy Harsh Strong Thin/ small Thick/ heavy Black (ink) Blue (ink) Dark Bold Black Bumpy Rough Grainy Dry Watery Shiny

The intention to reproduce the extracted information presented in Tables 3-3 and 3-4 is mainly to facilitate further discussion in treating the data for implementation purposes. It should be highlighted here that because this research project does not focus on the graphical aspect of drawing, the visual cues presented in Table 3-4 will only be analysed to adequately assist in the integration of the identified haptic cues. The analysis on the visual features includes consideration of line width produced by the pen-like tools. This may somehow affect the user experience when evaluating the haptic interfaces.

3.5 Refining the Cues for Simulation

In order to benefit from the extraction of cues presented in Tables 3-3 and 3-4, a set of parameters, which integrates both the tactile and visual elements, needs to be established. One way of doing this is by examining the haptic feedback received during the drawing interactions for each combination of pen-like tools on paper types. In other words, a library of haptic features is established based on the drawing experience performed by the experts. From this study, such compilation of haptic and visual cues for a combination of the pen-like tools used on a smooth paper is presented in Table 3-5.

TABLE 3-5: HAPTIC AND VISUAL CUES ON A SMOOTH SURFACE

PEN-LIKE TOOLS			PRESSURE APPLIED	
			Low (i.e. Press)	High (i.e. Push)
Pencil	Thin tip	PCL5	**Hard**	**Hard, Smooth, Sharp/ Scratchy, Stiff, Bumpy/Rough**
			Light, delicate, smooth	*Thin/small, delicate, smooth*
		PCL7	**Soft**	**Smooth, Flow, Soft, Glide, Silky**
			Thin/small, light, soft	*Smooth, dark, thick/heavy, uniform*
	Wide tip	PCL6	**Soft**	**Smooth, Soft, Glide, Silky**
			Thin/small, soft	*Thick/heavy, dark, bold, distorted, black, smooth*
Pen	Thin tip	PN4	**Hard**	**Sharp/scratchy, Hard, Stiff, Bumpy/rough, Smooth**
			Light, thin/small	*Strong, dark, distorted, thick/ heavy*
		PN3	**Soft**	**Smooth, Flows, Soft, Velvety, Scratchy, Sticky**
			Light, watery	*Smooth, thin/small, thick, uniform, dark, bold, black*
	Wide tip	PN1 & PN2	**Soft**	**Smooth, Flows, Glide, Velvety, Silky**
			Light	*Uniform, thick/heavy, smooth, bold, strong, dark*
Crayon		CR8	**Sticky, soft**	**Smooth, Flows, Stiff, Glide, Velvety, Creamy, Sharp/scratchy**
			Light, soft, thin/small	*Thick/heavy, distorted, bold, black, dark, strong, smooth*
Charcoal		CHAR	**Dry, soft**	**Smooth, Rough, Velvety, Hard, Sharp/scratchy**
			Thin/small	*Black, distorted, dark, thick/ heavy, smooth, strong, bold*

[Note: Tactile cues are in **BOLD**; visual cues are in *ITALIC*]

Table 3-5 shows the type of pen-like tools used with their respective haptic and visual cues perceived whenever force is applied during an interaction on a smooth type of paper. The larger column entitled 'Pressure Applied' comprises all of these cues. Regardless of the pen-like tools used, the first column in the 'Pressure Applied' contains the cues when the action "press" as noted in Table 3-3 is performed whereas the second column holds information on the action "push".

The shaded rows in Table 3-5(a) will be used to illustrate a simple example of a relationship between the pen-like tool chosen, the haptic interactions involved and the cues obtained. As an example, using a thin-tip pencil (PCL5) for drawing on a smooth paper an artist applied a very minimum force (haptic interaction - press) on the paper, which felt **hard** from the interaction, and simultaneously visualised a *light, delicate*, and *smooth* mark. As the interaction continues, the artist applied a higher pressure (haptic interaction - push) and felt the sensation of **hard, smooth, sharp/scratchy, stiff,** and **bumpy/rough** depending on the pressure applied. (In this context, the interaction "press" is associated to a passive touch whereas "push" is related to an active exploration on the drawing surface.) The series of tactile information shown in this table is ordered in a manner that is based on the number of artists using the vocabularies. As an example, more artists during the study noted that interacting using a PCL5 on smooth paper is hard but fewer said that the interaction is bumpy/ rough. More detailed information pertaining to this table is presented in Appendix 3-6. The variation of sensation showed in this table also implies the difference of individual perceptions on an object (pen-like tool on paper interaction). A similar explanation as used for PCL5 on a smooth paper could be applied to other pen-like tools in this table too.

The information of the haptic and visual cues for interactions on a textured surface was also compiled. A similar technique in presenting the information is followed and is shown in Table 3-6. A detailed summary of haptic and visual cues for this table is also presented in Appendix 3-6.

TABLE 3-6: HAPTIC AND VISUAL CUES ON A TEXTURED SURFACE

PEN-LIKE TOOLS			PRESSURE APPLIED	
			Low (i.e. Press)	High (i.e. Push)
Pencil	Thin tip	PCL5	**Hard**	**Hard, Bumpy/rough, Stiff, Flows, Sharp/scratchy**
			Light, thin/small	*Light, smooth, distorted, Soft, thin/small, Thick/heavy, dark*
		PCL7	**Soft**	**Sharp/scratchy, Smooth, Bumpy/rough, Stiff**
			Thin/small	*Dark, smooth, distorted, thick*
	Wide tip	PCL6	**Soft**	**Stiff, Glide, Bumpy/rough**
			Soft, light	*Distorted, thick/heavy, black, dark, grainier, shiny, bold*
Pen	Thin tip	PN4	**Hard**	**Sharp/scratchy, Bumpy/rough, Hard, Stiff, Smooth**
			Delicate	*Light, distorted, thin/small, Bold*
		PN3	**Soft**	**Sharp/scratchy, Bumpy/rough, Stiff, Smooth**
			Light	*Dark, Thick/heavy, Strong, Thin/small, Broken, Bold*
	Wide tip	PN1 & PN2	**Soft**	**Stiff, bumpy/rough, Sharp/scratchy**
			Light	*Distorted, bold, thick/heavy, dark*
Crayon		CR8	**Sticky, soft, dry**	**Smooth, Bumpy/rough, Glide, Velvety**
			Light	*Thick/heavy, broken, dark, black, rough, distorted, bold, uniform, grainier*
Charcoal		CHAR	**Soft, dry**	**Smooth, Bumpy/rough, Sharp/scratchy, Stiff**
			Light	*Distorted, broken, grainier, dark, black*

[Note: Tactile cues are in **BOLD**; visual cues are in *ITALIC*]

From Tables 3-5 and 3-6, the interactions using different pen-like tools on paper types produce various tactile feedbacks. It is implied in this study that the tactile sensations perceived mainly depend on the interaction of the tool and paper combination. It should be noted that in this study, similar sensations have been felt when using PN1 and PN2. For simplicity purposes only PN1 will be referred to in the following investigation of this research.

By examining both sets of tactile sensations from Tables 3-5 and 3-6, a pattern could be drawn from this compilation of cues. The tactile sensation obtained from this study could be grouped into three main dimension cues, namely: the bumpiness, scratchiness and stickiness of an interaction. These labelings were derived from the root names of the tactile sensation resulting from the artists' responses. The root names chosen represent closely the other members of haptic features in a particular group. From this examination, the bumpiness dimension includes the 'rough', and 'rough/bumpy' sensation of the drawing interaction, scratchiness consists of the 'hard', 'dry', 'stiff', and 'sharp/scratchy' elements, and stickiness has 'sticky', 'creamy' and 'velvety' feeling. From the user experience gathered the smooth sensations, which include 'smooth', 'silk', 'flow', and 'glide' could be considered as the other end of each dimension cue specified. It is a neutral point of these three dimensions. A 2D illustration of this relationship is presented in Figure 3-1.

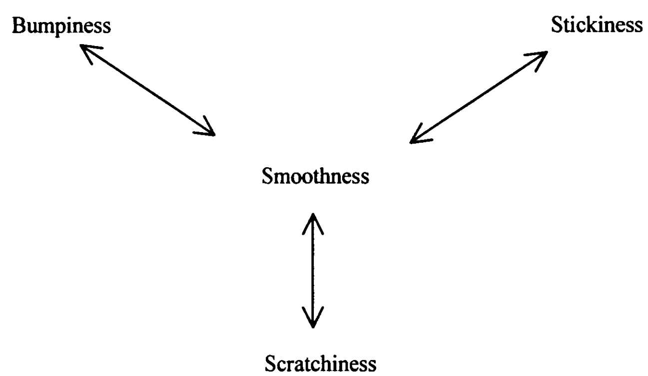


FIGURE 3-1 HAPTIC DIMENSION CUES AND NEUTRAL POINT (TOP VIEW)

Figure 3-1 is a simplified association between the bumpiness, scratchiness, stickiness and smoothness sensations. In reality, the relationship is more complex than that presented in this figure. A drawing interaction should encompass an appropriate mixture of all the dimension cues to obtain a more realistic tactile feeling. Taking the pencils example from Table 3-5, one could say that an interaction using a PCL5 on a smooth paper could produce a tactile sensation of scratchiness and bumpiness. On the other hand, using a PCL6 on smooth paper creates a smooth feeling which is at the other end of the dimension cues. If these haptic dimension cues are important, how do we justify their validity and appropriateness for a drawing application?

3.5.1 Validating the Haptic Dimension Cues

In determining the appropriateness of the haptic dimension cues, closed card sorting was conducted to confirm the relationship between smoothness, a neutral haptic sensation point for a drawing interaction, and the other three main cues proposed i.e. bumpiness, scratchiness and stickiness. The card sorting activity conducted was aimed towards understanding what others perceived by the terms 'bumpiness', 'scratchiness' and 'stickiness' cues with respect to drawing and sketching interactions based on their own experiences interacting in the real world. The validation process also included checking the label given to the dimension cues and the relationship between them.

Fifteen evaluators (nine males, six females) performed the card sorting exercise in which they were individually tested. These evaluators were non-artists, recruited among the staff at University College London and several students from other colleges in London. Since the main activity involved working on the existing haptic terminologies compiled from the previous group of artists, it was not considered necessary to recruit from the artists' population.

During the exercise, evaluators were asked to fill in the definition form to describe their understanding of the terms "smoothness", "stickiness", "bumpiness", and "scratchiness" with respect to a drawing and sketching interaction (Appendix 3-7). They were then given thirty cue cards each with a tactile cue obtained from Tables 3-5 and 3-6 written on it. A list of vocabularies used in the card sorting activity is presented in Appendix 3-8. The evaluators were asked to place the cards according to the appropriate group headings (i.e. 'bumpiness', 'scratchiness' and 'stickiness'). A cue card can be placed into more than one group or may not necessarily belong to any of these three groups. In such cases, the evaluators were asked to formulate their own group title. Evaluators were then required to rank the cards grouped according to their appropriate level (e.g. from being 'low' to 'high' bumpiness). All evaluators were asked to comment on the appropriateness of the label given to the three groups.

The overall findings revealed that almost all evaluators agreed with the naming of the three haptic dimension cues to represent the vocabularies of tactile sensation for a drawing interactions provided to them. Only Evaluator No. 7 has a reservation with the term "scratchiness" as she argued that the term "roughness" would be more appropriate.

The findings also uncovered that 10 evaluators (i.e. Evaluator Nos. 3, 6, 7, 8, 9, 10, 11, 12, 14 and 15) said that the lower end of the 'bumpiness' group should be the tactile sensation that feels smooth. For the 'scratchiness' group, 2 evaluators (i.e. Evaluator Nos. 1 and 10) said that at first a drawing interaction should feel smooth (e.g. 'slide', 'flow', 'flat', and 'waxy') and then the sensation should become more severe in terms of its scratchiness. This opinion differs from the rest of the evaluators who think that mainly the feeling should be initially dry. In the case of the 'stickiness' group, 10 evaluators (i.e. Evaluator Nos. 1, 4, 5, 8, 9, 10, 11, 12, 14, and 15) said that the interaction feels smooth at first and becoming stickier later. However, a few evaluators suggested that a new dimension to group the smooth sensation should be formulated. Two evaluators (i.e. Evaluator Nos. 2 and 14) said that cue cards that consist of the smooth feedback should be separated in a new dimension called 'smooth'. Evaluator Nos. 2, 5 and 13 proposed that this group should be the opposite of the 'bumpiness' dimension.

Based on the fact that the majority of evaluators agreed on the naming of the three haptic dimension cues and the position of the smooth sensation in the three dimension cues, it could be said that the three haptic dimension cues are appropriately confirmed for a drawing interaction with the smoothness sensation as a neutral point of these cues.

3.6 Discussion

A main strength in this study is the development of a preliminary taxonomy of haptic features for a drawing domain. The study has demonstrated how the understanding of user haptic experience and perception presented in Chapter 2 can be used to obtain haptic cues in a drawing interaction. Artists' haptic explorations (Section 2.2.2) to assess the material properties of an object (i.e. interaction between the pen-like tool and the drawing surface) have been investigated. The way we describe the tactile sensation from the interaction that we touch and feel (Section 2.2.2) has assisted in finding the haptic features for a drawing interaction. This preliminary taxonomy has addressed the first research question in this thesis, which are the haptic features involved in a drawing domain.

The study findings have revealed the relevant visual features associated with the haptic interactions involved. With a drawing activity, both visual and haptic sensations play an important role. This has been highlighted and discussed in Section 2.4.1. Even though this research project does not focus on visual feedback, the proposed cues that emerge with respect to the haptic elements could be used by others. The haptic and visual features proposed are targetted specifically to the haptic sensation and the associated visual cues of the drawing interactions.

At present, due to limited haptic technology available, not all of the haptic features suggested could be implemented in a computer environment. In this case, those haptic elements that correspond to the "hand & tool", and "hand & surface" type of haptic interactions proposed in the taxonomy may require special devices to generate the haptic sensation. The identification of the three haptic dimension cues suitable for drawing applications and the technique used to validate them demonstrates how to use the taxonomy for a computer drawing environment. This identification addresses the second research question in this thesis, regarding the haptic features suitable for a drawing application. It also leads to questions of a suitable haptic device to be used for a haptic drawing application, and how to present such haptic information to an interface design that could meet users' satisfaction.

Despite the points described regarding the taxonomy, a limitation in this study is that a small number of pen tools and paper types have been tested. If a different group of artists are researched a variation of terminologies may be established.

3.7 Chapter Summary

This chapter has proposed some possible haptic features for the drawing domain. The study presented in this chapter has involved understanding artists' experience and perception in using pen-like tools on paper types for drawing. The systematic approach taken towards relating haptic features to user actions in the drawing process has shown which haptic cues to apply in an interface design for a particular user action, so that appropriate haptic feedback can be provided to the users. This study has also presented the haptic properties and features for a drawing interaction. A hierarchical representation of haptic cues, in terms of the properties and their features, is explicitly presented. The level of detail enables an interface designer to distinguish between the set of tactile properties and their features. The categorisation of haptic cues also delineates the range of features for a particular haptic property.

In this chapter, the compiled tactile sensations that have resulted from this study have been refined so that they can be applied in the development stage of a computer-drawing application. A pattern in terms of the grouping of dimension cues has been identified from this compilation of tactile feedback. The bumpiness, scratchiness and stickiness dimension cues are considered important in this investigation and should be taken further in this research project.

From this chapter the proposed preliminary taxonomy of haptic features has answered the first research question of the thesis while the identification of the three haptic dimension cues has answered the second. This leads to choosing a suitable haptic device and rendering technique to be used to generate the suggested haptic feedback.

Chapter 4 Review of Haptic Systems

4.1 Introduction

The aim of this chapter is to present a background understanding of the relevant aspects of technology involved in the existing haptic interface design studies. The intention is to find a suitable haptic device to simulate the haptic sensation identified as important to a computer drawing application (Chapter 3). This chapter is the second part of the literature review in this thesis that aims to establish substantive knowledge towards answering the research questions stated in Chapter 1.

The chapter examines the relationship between haptic rendering and force perception. The understanding of how force perception works prompts an investigation that reviews current haptic devices. This leads to focusing towards the PHANToM haptic device, which is used in this research project. A review of haptic applications other than art-related systems, which involve using the PHANToM haptic device, is then presented. This is intended to find out how in general haptic feedback has been integrated into a computer system. To complete this observation, a review that specifically focuses on examining art-related studies is presented. The chapter continues by presenting an overview of the PHANToM haptic device in relation to techniques used for rendering force feedback. This chapter emphasises the haptic device and the rendering technique to be used in this research in order to simulate the haptic feedback identified in Chapter 3.

4.2 Haptic Rendering and Force Perception

In general, the process of computing and generating forces in response to user interactions with virtual objects is called haptic rendering (Salisbury et al, 1995). The goal of such a process is to enable a user to touch, feel and manipulate virtual objects through a haptic device (Basdogan and Srinivasan, 2001). The generated force feedback perceived may result in users understanding and accepting the haptic modelling designed for the system.

Richard and Cutkosky (2000) note that haptically rendered friction affects subject performance in a manner quite similar to that of real physical friction. This finding is drawn from their study in which they investigated the effects of real and computer generated friction on human performance in a targeting task. The study involved a user acquiring a target by moving a cursor to the location of the target and pressing a button upon completion of the task. However, they caution that due to the complexity of the implementation using existing haptic technology, the tactile sensation in a computer environment could not be comparable to that of reality. Hayward et al (2004) support this argument and highlighted the difficulties in producing a perfectly "realistic" haptic interaction. Scali et al (2002) raise some issues on compromising between cognitive demands and the technologies available. They question how much "reality" is adequate to support tactile and force-feedback for design purposes. The answers to this question depend on the haptic device to be used and the context in question.

When discussing human perception and haptic devices, Hayward et al (2004) provide an example of how we perceive a visual scene from a sequence of high-resolution digital movie images. The temporal sensitivity of our visual system is not adequate to detect the fast presentation of the movie frames nor can it determine which individual pixels have resulted in a perception of a visual scene that is similar to our daily experiences. Hayward et al equate this example with a haptic simulation whereby an update rate of 1kHz or more enables us to feel continuous haptic feedback; hence, creating an illusion of touching a hard object. Different haptic device may differ significantly in terms of the update rates. Hayward et al argue that even with an "imperfect" haptic device, a user could quickly adapt to such limitation of the haptic rendering and naturally associates the sensation to everyday experiences such as perceiving surface texture and shape of the objects through touch. This argument is supported by a statement by Jansson and Ivas (2000) that an admirable capability of human beings is to be able to adapt to a new artificial environment in a technical context.

Okamura (2001) emphasises that haptic exploration is a mechanism by which we learn about surface properties of unknown objects. These attributes include the object shape, surface texture, inertia and stiffness. In the context of a drawing application, when a probe explores a drawing surface, the users should be able to feel various tactile sensations from a drawing process. Such variations depend on the paper or material used. Also, the way these sensations will be perceived and interpreted by the users is based on their previous understanding of interactions in a similar context. In implementing haptic feedback that aims towards users' subjective satisfaction when exploring the object, the perceptual aspects based on the rendering technique should be emphasised. One way of making the tactile sensations be felt during an interaction is by considering the haptic cues as part of the properties of an explored object (drawing surface).

From the multi-sensory interaction model illustrated in Figure 2-1, the physical interaction model and the physical haptic device elements are sandwiched between the layers containing the user and the environment aspects. This situation indicates that both elements have a close relationship that links the users with the environment. With regards to this model, the knowledge of how the physical world works has been used to render the force feedback in a computer environment. Also, the available technologies that could support the implementation of haptic effects need to be understood because such rendering depends largely on the device to be used as well. By trying to understand the capability of the device, a suitable haptic simulation could be implemented. In light of this, there is a need to examine the existing haptic devices before a decision could be made in terms of choosing a suitable device to support drawing interactions in this research project.

4.3 Review of Haptic Devices

The earliest haptic device being introduced for computers is the Braille reader (Kay, 2006). This tactile haptic device has a line of metal pins which represents an on-screen line of text in a Braille format. A visually impaired user will have to move their fingers on these metal pins in order to understand the information on the computer screen. Following from the Braille reader, there are many other force feedback devices that use haptic technology for entertainment purposes. Among these devices are joysticks and gaming controls (Hannaford et al, 2002). There is a shift in trend now that the usage of haptic feedbacks has been extended from entertainment (i.e. gaming applications) to other task related fields such as training and education purposes (e.g. Hayward et al (2004); Laycock and Day (2003)). One of the reasons is the emergence of new haptic devices in the market.

Usually, a haptic device employed in a particular application could support tasks involving either tactile or force feedback. In this context, the term "tactile feedback" is used when pertaining to the cutaneous sense but more frequently the sensation of pressure; whereas, "force feedback" is related to the mechanical production of information sensed by the human kinesthetic system (McGee, 2002).

In general, haptic devices can be categorised into three major types based on their physical features: body-based devices, ground-based devices and tactile displays (Computer Science Dept, University of Utah, 2003). The body-based devices can be further classified as having flexible features (e.g. those features in CyberGlove) and rigid features (e.g. Virtual Reality Bodysuit). The ground-based devices can be in the form of joysticks/ hand controllers (e.g. XL Action Controller, CyberImpact Joystick, PHANToM), keyboards (e.g. regular computer keyboard, point-of-sale keyboard), mice (e.g. two-button mouse, three-button mouse, custom mouse), sophisticated teleoperation masters (e.g. Sarcos Dextrous Arm

Master) and trackballs (e.g. trackball mouse). Finally, some examples of tactile haptic devices include microelectromechanical actuators, CyberTouch and TouchMaster (see Burdea, 1999, 2003).

A further understanding of classifications of the haptic devices in terms of the kind of feedback that they can support is also important. For example, CyberTouch and TouchMaster are useful in supporting tactile feedback. On the other hand, CyberGrasp, Dextrous Arm Master and PHANToM are useful for force feedback. Besides considering the task and context in question, such knowledge on supporting various type of feedback is necessary when one is deciding an appropriate device to be used in a haptic application. Beside the problem of higher production cost, the interaction designers need to consider other current issues of haptic devices. Burdea (2000) discusses some technical limitations the current technology has which include the limited workspace of desktop devices, the large weight of force feedback gloves, the lack of force feedback to the body and safety concerns when wearing these devices.

In response to the technical limitations in the haptic technology, Laycock and Day (2003) report a comprehensive review of recent developments and applications of haptic feedback devices. They also examine how such feedback has been combined with visual display devices in order to improve the immersive experience. The review provides guidance on the haptic technology available which includes the producers, usage, market price, relevant product review or evaluation reported, and examples of applications in which the device has been used. The technology covered in the review ranges from a desktop device type of equipment such as the force and tactile feedback mice to a locomotion interface such as the Sarcos Treadport. Another complete review on haptic technologies that could assist designers in choosing a suitable haptic device in terms of its technical capabilities could be found in Hayward et al (2004). The review describes distinct properties of haptic devices. Hayward et al stress that, like any other kind of visual and audio displays, haptic devices can take advantage of both the strengths and the limitations of human perception. Some examples of application domains in which the use of haptic feedback could benefit the users are also provided in the review.

Various force feedback haptic devices have been introduced in the market. Haptic devices such as PHANToM (Massie and Salisbury, 1994), Logitech WingMan Force Feedback mouse (Brewster, 2005) and Pantograph (Campion et al, 2005) have been widely used by researchers to aid haptic interactions. Oakley et al (2000) highlight that no formal evaluation of these haptic devices in terms of their effectiveness in supporting interactions has been performed. Following from this, some formal evaluations on the usability of these two haptic devices have recently been carried out by Yu and Brewster (2003). They noted that Logitech

WingMan Force Feedback mouse is effective for receiving haptic feedback for 2D objects but the PHANToM is more suitable for 3D objects. However, the suitability in selecting haptic device for the use in a computer application is still questionable due to the limited information on this usability evaluation.

With little information on the effectiveness of haptic devices, interaction designers are left with a big task. This is to decide suitable devices to support haptic interactions. The decision gets difficult with the fact that most current haptic devices available in the market are still very expensive. It is reported that at present, one haptic device may not be able to support all haptic perception (McGee et al, 2001a). For example, the PHANToM haptic device and WingMan Force Feedback mouse are meant for supporting force feedback (Yu and Brewster, 2003). However, because of limited functionalities in current devices, PHANToM and the WingMan Force feedback mouse have also been used to represent tactile feedback (McGee et al, 2001a; Yu et al, 2002). This has raised a common question in interface design, which is whether a new technology should be adapted to users or the other way round. As noted in Section 4.2, to a certain extent human beings have the ability to adapt to new or even artificial environments after extended practice. The idea of substituting a device with another and expecting the user to adapt to a new environment is not new, and has commonly been practiced. Even though this is the case, one should avoid designing interfaces in which users have to adapt to the technology (Norman, 2005). Interface design should be user-driven and there is a need to ensure its usability. In order to handle this situation and obtain acceptable haptic feedback, other modalities have been incorporated in the interaction. For example, McGee et al (2001a) integrated audio in the interface design to complement haptic interaction in determining textural information. They concluded that multimodal augmentation is a potential method for improving the simulation of force feedback textures.

In selecting a suitable device for haptic interactions, Lederman and Klatzky (1999) urge interaction designers to understand in advance the control character of a particular haptic device in use. They emphasise that designers are expected to know how to select an appropriate range of stimuli in association with this device. This is especially important when one is using a device, which is not meant to support the intended haptic feedback as noted in McGee et al's (2001a) work. For example, when using the PHANToM, the interaction designers need to realise that this device can only provide a one-point contact of information at each time (Jansson and Billberger, 1999). They have to know what sort of haptic information could or could not be supported by this device. If the designers are very well versed in the capabilities of a device, they are able to manipulate fully the functionalities of the device in use. This can result in better support for the haptic interactions.

With regard to choosing a suitable haptic device for a drawing interaction, ideally two important criteria that need to be considered are: a tool that feels 'right' and 'natural' in the hand of the users, and the one that could provide an appropriate haptic feedback for an interaction acceptable to those in the real world. An acceptable balance between both criteria is needed to create an acceptable environment. In such a case, the environment in which the device is to be used plays an important role in a decision making process. For example, even though a mouse is widely used as an input device, due to its nature, it could not support drawing activities efficiently (Trinder, 1999). Unlike the mouse, a WACOM tablet and pen is an example of interaction tools, which enables users to draw more naturally. A more sophisticated tool could be seen in the pen-like PHANToM haptic device in which the users could feel the force feedback from the interaction. The usage of the PHANToM has become popular and frequently found in a computer environment. There are many research initiatives which are investigating the usage of this pen-like tool in drawing applications such as in the work reported by Curtis et al (1997), Sousa and Buchanan (2000) and Yu et al (2002), to name a few. In terms of the feedback received during a drawing interaction, a WACOM tablet gives a sensation of a rigid pen on a hard surface whereas a PHANToM allows programmable forces to be simulated to obtain softer and harder sensations (Baxter et al, 2001).

In this research project, the PHANToM haptic device is utilised for haptic interactions. One main reason is its availability at the Computer Science Department, hence, a feasible reason to use it for this research project. The fact that PHANToM is more suitable for force feedback interaction suggests the importance of examining its usage in various haptic applications.

4.4 Review of Haptic Applications

This section presents studies pertaining to haptic feedback and interactions, mainly using PHANToM haptic device, in various systems. The intention is to find out if the issue of providing haptic design options as noted in Section 1.1 has been addressed, and also to examine how the haptic feedback has been evaluated in the reported studies. This review is also to investigate how well PHANToM could support haptic interactions, especially in the art-related applications. To systematically present the literature research findings, two parts of review will be conducted: those haptic systems other than art-related work, and art haptic and graphical applications. The purpose of examining those studies in the non art-related work is to learn from this area in order to better understand how haptic feedback has been used.

4.4.1 Haptic Applications Other Than the Art-Related Systems

This section presents a review on haptic research work, which includes systems for medical training, visually impaired people, online communications, weather forecast information and a driving environment. These are the areas in which the benefits of having haptic feedback in the systems are more obvious than those in art-related applications.

Medical Applications

In the area of medical applications, effort that has shown how haptic feedback is integrated in the applications could be found in Crossan et al (2000; 2001; 2002). Crossan et al (2000; 2001) describe their work about the concept of multimodal cues to assist training in a medical simulator. They argue that little work has been done on guiding a user during the simulation. They propose the implementation of the cues and their integration into the Horse Ovary Palpation Simulator (HOPS). The intention was to provide guidance and performance feedback to the user in the form of multimodal cues in terms of haptic, graphic and auditory feedback presented during a session of simulator training. With regards to the haptic cues, the firmness of the ovary was modelled with a linear force model.

In subsequent work, Crossan et al (2001) tested the HOPS system by conducting a comparison study on ovary training over different users' skill levels. The performance of a group of experienced large animals veterinarians (skilled users) were compared with a group of second year veterinary students (novice users). The study result suggested that the novice users perform better than expected. In this work, Crossan et al noted that during the HOPS implementation, a selection of veterinarians were asked to set the softness, friction and damping properties for the models. This method was used to obtain a "good approximation" of actual ovary properties. However, in this study they only briefly mentioned that the softness cue was noted. Also they did not explain why only this cue was tested. Other work reported by Crossan (2003) on an evaluation of the HOPS simulator emphasised the importance of multi-session VR medical training. The study revealed that over four training sessions, participants improved their diagnosis accuracy when using the simulator. This result implies that haptic feedback integrated can be useful in a medical application. Through training, the haptic feedback can be made familiar to the users and will result in an improvement in the users' performances both in the computer envoronment and in the real world situation.

There are many other haptic research works in the medical area such as those reported in Torre et al (2004), Guerraz et al (2002), Morris et al (2004), and Sewell et al (2004). The studies focus on the technical aspect of haptics that includes improving the rendering in the systems. No discussion on the type of haptic cues involved is presented.

Applications for Visually Impaired People

Besides medical applications, systems for visually impaired people are also benefiting from haptic integration. There are many studies that include haptic feedback in applications for blind people. Ramloll et al (2000) and Yu et al (2001) aimed at making line graphs accessible to blind students through auditory and haptic media. In their preliminary work they described the design space for representing line graphs, and the technology to develop the prototype. Their technique in representing the line graph involves a raised (i.e. convex) surface design. Cylindrical geometry from the toolkit was used to create the line. They tested two curves with different friction characteristics i.e. (i) sticky and, (ii) slippery feedback. They found that using raised surface design is difficult to distinguish two different line graphs and proposed a groove surface design. In several subsequent reported studies, Yu and Brewster (2003) and Yu et al (2001) overcame this problem by using a groove (i.e. concave) surface design and proved that this design is better than its convex counterpart. Despite the difficulties in distinguishing the line graphs, Ramloll et al's (2000) study findings showed that subtle changes to the design of the haptic surface have significant effects on its effectiveness as a medium for data representation. Yu et al (2001) concluded that different surface friction characteristics such as sticky and slippery sensations are useful to distinguish different lines on a simple haptic graph.

The inclusion of haptic feedback has also been extended to online applications (Yu et al, 2002; Yu et al, 2003). Yu et al (2002; 2003) worked on web-based applications for blind people to create virtual graphs. Yu et al (2002) started by introducing a new development of a haptic Web-based graph construction tool that is able to create line graphs, bar charts and pie charts based on data entered by the users. Their intention was to conduct usability evaluation of the system. Yu et al (2002; 2003) confirmed the usefulness of the tools and their potential for blind people in several evaluation studies.

An application of haptics for visually impaired users is also reported in Brewster's (2005) "Senses in Touch II". The haptic system is about a museum exhibit for visually impaired users. Sjostrom's (2002) PhD work also provides another source of haptic demo applications suitable for blind users. These are some of the examples that have successfully employed haptic feedback in computer systems.

Systems for Computer Supported Collaborative Work

Systems involving collaborative work have also benefited from haptic feedback. Oakley et al (2001) started their initial investigation of haptic collaboration in shared editors. They argued that real-time collaborative systems suffer from difficulties in keeping users maintaining their awareness of the actions of others and meaningfully coordinating their work activities. They considered the usage of haptic feedback to address this problem and focused on graphical avatars, known as telepointers, in the synchronous shared editors. Telepointers are additional cursors used to represent the position of other users in the workspace. Oakley et al (2001) based their communication on enhancing interactions between these cursors. They defined five different mechanisms for haptic cursor communication, which are: push effect, gesture effect, locate and grab effects, and proximity effect. They concluded that the majority of users regard the communication as appealing and subjectively agreed the significant benefits of the integration of haptics.

The benefit of including haptics in collaborative work is also shown by Jordan et al (2002). In the study, they focused on a specific task to work in a collaborative haptic environment that has significant physical distance and number of network hops. The experimental subjects were to cooperate lifting a box together under several conditions, some of which included haptics. The study found that the sense of co-presence increased in the conditions where force feedback was provided.

Applications for Driving Environments, and Weather Systems

The integration of haptic feedback has also been extended to other domain of applications such as in a driving environment (e.g. Enriquez et al, 2001) and weather systems (Omata et al, 2005). For example, Enriquez el al (2001) studied the usefulness of a tactile interface in the automobile environment. This interface was augmented with the visual design currently used in the automobiles. They evaluated the effectiveness of such a system in alerting the drivers of a possible problem. In this study, Enriquez et al demonstrated that a haptic stimulus could attract attention to a situation that may be overlooked. On the other hand, Omata et al (2005) focused on modelling the haptic features in a weather information system. The system involves haptizing wind, which allows a user to feel scale and direction of wind by assigning reactive force to represent the scale and direction. Their work was motivated by an existing problem in the field of study that is users' difficulties in recognising wind direction when the scale of the wind is small. Omata et al showed that magnitude of the frequency change is able to represent scale of wind while constant reactive force represents a direction of the wind. They examined several tactile stimulations, developed a model of haptizing for wind and evaluated the system.

Other Systems

Several studies have focused on the integration of haptics into some specific aspects of general interactions on an interface. In such a case, the study findings may be transferable to most of the application domains e.g. medical, collaborative systems and art-related applications. One example can be found in Tahkapaa and Raisamo's (2002) work, which claimed that tactile feedback has become very common in user interfaces but the benefits obtained from this modality are still not clear. Tahkapaa and Raisamo (2002) investigated how tactile feedback could be used in target selection tasks when using a tactile mouse so that the feedback could support visual information. In their study, which focused on efficiency and user satisfaction, they did not find statistically significant differences in efficiency but subjective results indicated that users were strongly in favour of the inclusion of haptics. They surmise that it is possible to obtain a significant difference in the result should a different task be use in the investigation. This claim indicates that haptic feedback is very context dependent and need careful considerations in the design stage.

Unlike Tahkapaa and Raisamo's (2002) approach in terms of the scope of the study, Oakley et al (2001) broaden the investigation to a multi-interaction environment. They argue that although haptic feedback has been shown to be useful to a single target interaction in a user interface design, its usefulness is still questionable to multi-target interactions. They evaluated a system that has several design conditions, meant to support menu interactions. These conditions are: visual (menu items not haptically enhanced), haptic (the force feedback parameters were obtained from previous studies on single target interactions), and adjusted haptic (modified version of parameters in haptic condition). The study findings were in favour of the adjusted haptic in terms of the reduction of target selection errors made. This indicates the importance of providing the appropriate force feedback in the computer environment.

Wall et al (2002) also showed that study findings obtained in a specific user interface-oriented work could be applied to various generic domains. In their work, they tried to extend the principle of a 3D environment-targeting task as done by others such as Oakley et al (2001). The study involved the inclusion of haptic feedback, a "virtual magnet" that physically attracts the user towards the targets in the environment. Wall et al (2002) applied this feedback to a virtual sketching prototype in order to specifically evaluate the impact of this "virtual magnet" effect as a haptic tool in an experimental task. One of the study findings indicates that the haptic feedback improved subjects' accuracy in the task performed.

4.4.2 Art Haptic and Graphical Applications

The studies pertaining to haptic interface design in art-related work are those that are most directly related to this thesis project. This section describes how the understanding of human haptic systems has been applied to the relevant art-related research. In examining these studies, the benefits of haptic feedback integrated in the systems are also highlighted. The intention is to find out to what extent haptic feedback has been used in studies pertaining to artwork.

Research in art-related areas has successfully manipulated the force feedback in various application systems. It has been used in painting applications to give users natural control of complex brush strokes (Baxter et al, 2001; Lin et al, 2002). Baxter et al (2001) present a novel painting system, called DAB, with an intuitive haptic interface that is based on a 3D brush model. Their work was motivated by the awareness of the need to balance between the work of art produced from a creative process in general with the process of developing the system itself. In the study, when users apply force, they obtain tactile cues to the pressure being applied. The softness and hardness cues implemented enable the users to manipulate the paintbrush better. Such cues could increase the sense of realism in the interaction. The system was tested by several users and was reported to be easily and quickly learned even by a novice user. This finding is strengthened by Lin et al's (2002) discussion about the impact of haptics on the design of DAB and ArtNova. Lin et al (2002) continued Baxter et al's (2001) research work by examining the relationship between haptic interfaces and the process of creativity in digital design systems. They reflect on the evaluation of their haptic interface systems in terms of the design issues involved and lesson learned. Based on their further analysis from two earlier study findings of the systems, one of the points they argue is that a simple and natural haptic interaction based on real world interaction skills can help reduce a user's learning curve when using the system. For example, painting with a virtual brush is an interaction mode that makes use of real world interaction skills. Lin et al also claim that haptic interfaces could improve the level of usability of digital design systems and assist in capturing the feeling of being creative.

The ability to sense various tactile feedbacks during an interaction in a computer environment affects one's art-related activity experiences. In one such instance, Baxter et al (2001) stated that when users apply force on the interface they could feel the tactile cues to the pressure being applied. These cues enable the users to manipulate the paintbrush naturally, similar to the experience in the real physical world. Other tactile cues received can include the smoothness, stiffness and stickiness of brush strokes (Lin et al, 2002). Another study has reported that users can edit a painting and feel the material properties in a natural way (Kim et al, 2003). Kim et al found that the users were able to paint directly on a 3D model and that they could sense the thickness variation due to the added paint. They were able to feel the local material properties such as friction and stiffness of the interactions.

Haptic feedback has also been used in an interactive system for digital Chinese painting (Yeh et al, 2002). In this application, users could feel the viscosity, friction and bending force of the brush touching the paper. Yeh et al conducted a pilot experiment in which the findings indicated that brush writing with haptic feedback is better than that of the same visual display without haptic feedback. This study result suggests that the haptic feedback perceived has influenced the users' preference and acceptance towards the application.

There are many other art-related applications that have applied haptic feedback in the systems but not focusing specifically on the cues involved. For example, Tano et al (2004) developed a 3D Sketching tool that allows users to draw using a PHANToM. They argue for a need to fully understand how people behave when sketching in three dimensions due to some common reported problems in 3D drawing such as difficulty of depth perception, poor sense of balance, and instability of drawing in midair. The study focus, which is not haptic cues, is also seen in other work such as in Guerraz et al's (2003) Texture Touch, Johnson et al's (1999) painting textures system, Chu and Tai's (2002) 3D painting, Lu et al's (2002) Virtual Sculptor, Snibbe et al's (1998) Dynasculpt, Wall et al's (2002) Virtual Sketching prototype, Bergamasco et al's (2002) Museum of Pure Form system, and McLaughlin et al's (2000) Haptic Museum. All these studies recognise the benefit of haptics in a computer application, but have not taken explicit account of user perceptions in their development.

4.4.3 Implications of the Studies Reported to this Thesis

When designing a haptic system to meet users' satisfaction, an investigation to seek for the users' preferences during the requirement analysis stage needs to be included. The implementation of the system should be based upon users' preferences towards a particular haptic feedback. To cater for various users' haptic preferences in a design is very complex as one person's liking may differ from another. In Section 1.1, it is noted that Yu et al (2003) suggested that options be provided to the users so that they can customise the force to fit their needs. From the literature findings of haptic applications presented in Sections 4.4.2 and 3.4.3, it is still not clear how these options should be presented to the users. What is the preferred haptic interface design that should be deployed and on what basis should it be chosen?

In terms of the evaluation tasks conducted involving the haptic feedback used in the work presented in Sections 4.4.1 and 4.4.2, the user haptic experience was not a main concern in the investigations. If user experience is an important factor in system design as emphasised in Chapter 2, by focusing less on this aspect, particularly on users' satisfaction towards the haptic sensation, may result in missing some relevant information to improve the haptic system.

The evaluation studies reported from the haptic applications have also shown that task conditions which include haptic feedback are better than those without (e.g. Jordan et al (2002), Yeh et al (2002) and Wall et al (2002)). In art-related applications, such as DAB, a positive user satisfaction has been reported when using the system whose underlying haptic features mimic reality. On the other hand, perhaps applications such as that used in Tano (2004) on 3D Sketching, which involves only the same haptic cue provided through out the interaction, may result in users still feeling satisfied when interacting using the system. Here, a question pertaining to a user preference in terms of whether a "fixed" haptic sensation, probably similar to the case of the 3D Sketching, is adequate for a drawing interaction or whether a "varied" haptic sensation that could be controlled by the users need to be investigated. This issue needs to be addressed in order to avoid spending so much development time in presenting haptic information, which in the end may not necessarily for acceptance.

In general, the studies presented in Sections 4.4.1 and 4.4.2 have indicated the benefits of haptic feedback for both non-art related and art related applications, respectively. Most of these applications used the PHANToM for haptic interactions. The findings indicate that despite the haptic device meant for force feedback interactions, it is still capable to generate subtle haptic sensation, especially in the art related applications, acceptable to the users. Also, it has been reported that a few studies, such as in Oakley et al (2001), and Wall et al (2002) presented in Section 3.4.1, have creatively used the haptic feedback generated from the PHANToM in their haptic designs resulting in users' acceptance of the feedback. The findings reflect the urge in needing to understand the functionality of a particular device in order to exploit its capabilities as presented in Section 4.3. This leads to a need to understand better about the PHANToM haptic device.

4.5 PHANToM for Pen-like Haptic Rendering

To present haptic cues using a PHANToM requires an understanding of how the device works. This section presents a brief overview of the device and provides supporting evidence that it is suitable to be used for haptic interactions. The section also explains how the force feedback is generated so that users could feel the force sensation during an interaction. The intention is to identify a suitable haptic rendering technique to be used in this research project.

4.5.1 The Capabilities and Operation of a PHANToM

PHANToM (Personal Haptic Interface Mechanism) is a haptic device that makes it possible to touch virtual objects in a computer environment (Massie and Salisbury, 1994). It transmits force to our hand or fingers and can mimic the sensation of touching real objects. The transmission can create an illusion of touching or manipulating solid physical objects.

The PHANToM is an electromechanical desktop device that can connect to a computer's input/ output. It has a moving arm ending in a thimble where the user can insert their index finger. A stylus can replace this thimble, enabling the user to feel the tip of the stylus touching virtual objects. Massie and Salisbury's (1994) technical design of the PHANToM is based on principles including relatively low mass, low friction, low backlash, high stiffness, and good backdrivability. This enables the PHANToM system to provide convincing sensations of contact, constrained motion, surface compliance, surface friction, texture and other mechanical attributes of virtual objects. Figure 4-1 shows a user holding a PHANToM stylus whilst interacting with a haptic system.

FIGURE 4-1 USING A PHANTOM

The stylus can track the motion and position of the user's fingertip whilst providing force feedback to the user. The PHANToM moving arm has position sensing of 6 degrees of freedom (x, y, z, pitch, yaw, roll), and a workspace of 60mm width, 130mm height, and 130mm depth. The computer connected to the PHANToM reads the position of the stylus each millisecond. The PHANToM provides a single-point of contact of haptic information upon touching a virtual object. A constant rate of force feedback provided enables users to perceive a hard contact. This is handled by the PHANToM Device Driver (PDD) that maintains a 1kHz servo update rate to ensure stable closed loop control of the PHANToM. The PHANToM device requires a minimum specification of a dual Pentium II 300, half a gigabyte of RAM, and a high-end graphics card with at least 32Mbytes of RAM (Em, 2000; SensAble Technologies, 2004).

The software used with the PHANToM interprets signals from the motion sensors located on the PHANToM's arm and sends information back to the motor that tells the thimble or stylus how much pressure is to be applied. This functionality enables users to virtually move about an object whose boundaries are being represented on the computer interface. Users are not able to penetrate into virtual objects that are solid, as if the stylus had collided with a real object. The capability of interpreting and sending back information to provide force feedback can facilitate access to the *x*, *y*, and *z* coordinates; hence, 3D images can be incorporated into a virtual scene.

The objects displayed on the computer screen are created by the software developer's kit, GHOST (General Haptics Open Software Toolkit) that works along with PHANToM. The GHOST SDK (Software Developer's Toolkit) is a C++ library of objects and methods and is used for developing interactive, three-dimensional, touch-enabled environments. There are several key features that this toolkit has to support haptic effects. These include the ability to:

- Specify the surface properties (for example compliance and friction) of the geometric models
- Support the generation of haptic human-computer interfaces, including haptic manipulators for interacting with objects in the haptic scene using force feedback and spatial effects such as spring, impulse, and vibration.

The toolkit does not generate visual representations of objects within the haptic scene graph. Graphics packages such as OpenGL work successfully with GHOST SDK to create such images. The toolkit does provide graphic callback mechanisms to facilitate integration between the haptic and graphic domains. In creating a visual effect, OpenGL provides predefined shapes, such as cubes, circles, and cylinders and allows software developers to place these objects anywhere on the screen. Such locations are determined by developers responsible for creating virtual scenes. To incorporate haptic feedback into a scene, GHOST SDK provides a high level C++ programming interface to generate haptic effects. These effects can be based on geometry (such as point haptic exploration), or force-time profiles (such as sinusoidal vibrations or jolts), or developers can define their own custom force fields. The toolkit supports a contact force model that consists of a force normal to the object surface calculated using a spring-damper model, and a force component tangential to the intersected surface computed using a stick-slip friction model. This contact force model enables developers to set several properties such as spring and damping constants, and coefficients of dynamic and static friction. This facility supports easy manipulation of force feedback in an environment. Like any other computer program, the haptic program must be compiled and debugged. Once compiled and error free, the developer could run the program and begin to actually feel the objects created with the haptic device.

4.5.2 PHANToM Haptic Device to Support Haptic Interactions

In a real-world context in which a typical drawing interaction is taking place, a pen-tool is usually used to draw on a paper surface. The moment the drawing implement touches the paper is the time when the users could feel the haptic feedback from their interactions. To replicate this behaviour on a computer environment using a PHANToM haptic device, the instant when the (PHANToM) cursor interacts with the (drawing paper) object on the interface should be the moment a haptic rendering process takes place. An interaction on this drawing paper can in fact be equated to haptic exploration behaviour on an interface using a haptic device i.e. PHANToM. As the haptic simulation is being updated at a rate of 1kHz, the user could perceive a constant signal continuous in time (Bordegoni, 2001), hence obtaining a feeling of the surface texture of the drawing paper upon interaction with PHANToM.

Many researchers have developed applications, which incorporate the PHANToM to assist in feeling the haptic feedback. In fact, almost all studies presented in Section 4.4 have used the PHANToM haptic device for interactions. Oakley et al (2000), in their work dealing with an investigation of the use of touch as a way to reduce visual overload in a conventional desktop, proved that the PHANToM is very effective in supporting kinaesthetic tasks. The usefulness of this haptic device is also seen in the work reported by Shillito et al (2001). They chose the PHANToM to be used in their creative 3D haptic system because of the maturity of this device in providing haptic feedback. Yu and Brewster (2002) confirmed the effectiveness of the PHANToM haptic device in supporting haptic interactions of 3D objects when they investigated the usability of force feedback devices in real applications. Ramloll et al (2000) used this device in their study and described briefly how its features can support their work. The PHANToM is described as taking the form of electro-mechanical devices constraining motions in space in a variety of ways to produce compelling haptic sensations. By holding a thimble or a stylus fixed to one end and some 'loaded' mechanical linkage, i.e. coupled with electrical actuators, a user can feel a reaction force which varies depending on factors such as the force applied by the user, physical properties of the virtual object touched and the position of the finger or stylus. The PHANToM simulates a single point contact with virtual objects accurately. Unfortunately, such feedback still results in a considerable reduction in haptic bandwidth when compared to the human's natural sensing ability. However, Ramloll et al argue that this haptic feedback is sufficient to enable users to manipulate and feel the virtual objects although detailed and realistic texture rendering is difficult under single point of contact. This is also in agreement with O'Malley (2002) who used PHANToM to study the comparison of human haptic size discrimination performance in real and simulated environments. He reported that performance of the size discrimination tasks in the virtual environment is comparable to that in the real environment, thus implying that the PHANToM is able to support simulating reality for these tasks.

4.5.3 Haptic Rendering Using the PHANToM

A lot of effort has been invested in topics about haptic rendering, resulting in many techniques to improve a rendering process in order to obtain a more realistic environment.One important focus of research is haptic rendering to generate surface texture sinceit is among the most prominent haptic characteristics of an object (Otaduy et al, 2004). Haptic texture rendering has obtained much interest recently following from Minsky's groundbreaking work on synthetic texture rendering using a two-dimensional force feedback joystick (Minsky, 1995).

In general, the goal of texture rendering is to evoke sensations related to various aspects of texture perception such as roughness and stickiness (Choi and Tan, 2000). The technique can be as simple as adjusting values of 'bumps' that represents the surface textures (Minsky et al, 1990) to something more complex involving algorithms, which adopt the god-object method (e.g. Melder & Harwin, 2003) whereby the technique involves keeping track of the intersections between objects during haptic interactions. The generation of forces should be based on a contact state in which these intersections occur (Okamura, 1998). In Section 2.2.1, it has been highlighted that according to Burdea (2000) the main elements involved in interaction behaviour are collision detection, object response such as surface deformation, hard contact simulation and motion constraints. From the range of haptic rendering techniques observed, it can be deduced that a simple rendering technique could involve both collision detections and a hard contact simulation. On the other hand, a more advanced approach may include a real-time haptic rendering that involves collision detection and/ or motion constraints.

Many studies have focused on haptic exploration and how users perceived the haptic feedback generated. Most of these studies utilised directly the capabilities obtained from the PHANToM haptic device when implementing the haptic applications. McGee et al (2001) highlighted that the force feedback received can be used to convey information regarding the relative perceived roughness of the textures. McGee et al (2000, 2001a, 2001b, 2001c, 2002) implemented the haptic textures by generating a series of sinusoidal waves or gratings on a rectangular patch on the back wall of a workspace. The resulting shapes of the texture depend on the amplitude and frequency of the sinusoidal waves. A sensation of bumpiness on a surface is a result of exploration using a probe over the peak of the waves. McGee et al's work has also shown that an increasing perceived roughness is obtained as the frequency of the texture increases. Wall and Harwin (2000) who used the same technique in implementing haptic effect noted that larger amplitude is perceived as a 'rougher' surface texture as compared to a smaller value.

The capabilities of the PHANToM have been used further for haptic exploration by manipulating the haptic parameters associated with it. Yu et al (2001) used the capabilities from the haptic device to implement the friction properties and surface texture for their application for blind computer users. The result through haptic explorations performed by the users indicated that both friction and surface texture were shown to be useful in distinguishing different objects presented on a line graph. Wall and Brewster (2003) continued the research by using the friction and stiffness parameters and spatial period of sinusoidal textures to assess haptic properties for data representation. Their work, which involves haptic exploration of a line graph in the environment, suggested that users' ability to discriminate a range of stimuli investigated was better when using friction rather than stiffness feedback.

There are other studies that employed more advanced rendering techniques in implementing the haptic feedback. For example, DAB system (Baxter et al, 2001) provides force feedback that imitates the sensation of applying brush strokes to a canvas. The force model used is based on a simple piecewise linear function of the penetration depth of the undeformed brush point. It involves manipulation of a spring constant during an interaction. When the brush contacts the canvas at a right angle, the stiff bristles act at first as strong compressive springs, sending an abrupt force to handle. As more pressure is applied, the bristles fasten and the compressive force reduces as bending forces take over. The compressive effects provide a lesser force when the brush makes a contact at an oblique angle. In this situation the simple piecewise linear function was extended to a piecewise Hermite curve in which case, the curve is defined by a series of control tuples that contain the penetration depth and corresponding force magnitude, and the linear stiffness of the spring model at a particular point. To complement the compressive effects, a tangential resistance was added by modeling the friction as a force opposite the current brush velocity. This force could influence users' perception in their ability to control the brush strokes.

Yeh at al (2002) adapted the algorithm used by Baxter et al. The difference is that Yeh et al used a bending spring concept rather than a stretch spring for the brush model simulation. In this case, an analogy of springs that adopt bending angle as the control variable was used. They argued that in the real world, bristles would not change their length when being pressed on a surface of a paper but they just bend as a result from the pressure applied. Yeh et al also included a mechanism to detect a collision between the brush and paper. Upon such collision, force information is sent back to the PHANToM to simulate the feeling that the user touches the paper. Gregory et al's (2000) inTouch system used a local deformation algorithm to allow users to edit and paint a polygonal mesh with a 3D haptic device. Kim et al (2003) later used this technique for their haptic editing of decoration and material properties.

Another example that involves a real-time haptic painting simulation is also found in Baxter et al's (2004) IMPaSTo, a realistic and interactive model for painting. Baxter et al present an interactive method for modelling paint media based on simplified physics and heuristics particularly tailored for use in real-time painting simulation. This simulation is based on a conservative advance algorithm that is an enhancement from the DAB system.

Deciding on a suitable rendering technique to support the haptic cues in an application is a challenge to a designer. In general, the studies that have used advanced rendering techniques and those that directly deployed the parameters provided by PHANToM haptic devices are aiming towards generating as realistic as possible haptic feedback for the users. In theory, a more sophisticated rendering algorithm should provide a better haptic sensation. However, the research findings have indicated that even a simple rendering technique, which involves manipulating the basic parameters of PHANToM such as in McGee et al's work, is capable in producing a haptic feedback that could meet users' satisfaction. The fact that none of the studies in haptic interface designs has addressed a complete set of haptic cues in a particular domain makes it reasonably appropriate to start with a simple rendering technique for this research project. This is demonstrated in Chapter 6 where the three haptic dimension cues (i.e. bumpiness, scratchiness, and stickiness) and their neutral point (i.e. smoothness) will be implemented.

4.6 Chapter Summary

This chapter has stated the choice of the PHANToM as a main device to be used in this research for haptic interactions. Justifications for the device based on its capability to provide satisfactory feedback during an interaction were presented. This chapter has also justified the haptic rendering technique to be used for generating the force feedback from PHANToM.

In justifying the choice for a haptic rendering technique, this chapter has reviewed how researchers used the concept of haptic texture rendering to provide appropriate force feedback for users during an interaction. This concept is important because it involves implementing haptic cues for an interaction. The notion of learning about the surface properties of an object through haptic exploration as presented in Chapter 2 is mentioned in this chapter. It has been noted that ideally a more sophisticated rendering algorithm should provide a better haptic sensation. However, it has been observed that even a simple texture rendering technique that manipulates the parameter values from the PHANToM is able to produce a haptic sensation realistic enough for the computer environment under study.

A review on haptic devices suggests that the PHANToM haptic device is appropriate for supporting force feedback interactions. This has made its choice suitable for applications involving tactile feedback such as in a drawing application. Reported studies have revealed the wide and successful utilisation of this device for interactions in supporting tactile sensation.

The reported studies presented have shown how haptic feedback has been used for interactions in various computer applications ranging from systems for medical applications to art-related work. Haptic interfaces have claimed to benefit users in artwork in terms of helping to capture the feeling of being creative. The haptic cues received during an interaction may support this. These claims were based on user subjective haptic experience when interacting with the art applications.

In augmenting haptic feedback to a computer environment, the research findings presented in this chapter have not addressed the way a particular sensation should be represented to users. An appropriate representation of haptic cues in terms of interface design is needed in order to obtain users acceptance of a haptic application system.

Chapter 5 Representing Haptic Information

5.1 Introduction

The aim of this chapter is to investigate how to represent haptic information into an interface design. The idea is to be able to make abstract haptic information concrete. This leads to an idea to integrate the three haptic dimension cues identified in Chapter 3 into a drawing prototype. This chapter provides the last part of the literature review whose aim is to establish a substantive knowledge in order to answer the research questions stated in Chapter 1.

The chapter presents an overview of metaphors in a computer interface design and how an understanding from this topic could be used to present haptic effects. A literature review to investigate to what extent metaphors have influenced user interface design in haptic applications is conducted. The findings suggest a pattern that provides an idea to present haptic information in a drawing interface. This leads to a brief examination on how a commonly available computer drawing application in the market presents an abstract concept on its interface design. The intention is to determine the way metaphors have been used as to support design to represent such abstraction. The findings are used to propose two types of interface design options, in terms of representing haptic information in a drawing application using the concept of metaphors.

5.2 The Importance of Metaphor

Embedding haptic feedback that involves intangible and abstract information into a system requires a careful consideration especially when presenting it on to an interface for users to interact with. This process is a challenge because developing a user interface where the program model matches the user model is not easy. In the case of haptic applications, users might not have a specific expectation of how the system works and the feedback they will get.

When dealing with a graphical interface, a common way to solve the problem of mismatch in user and system model is by using metaphors since they are able to provide a powerful way to communicate with the user, to link the mental models of the system designer and the user (Spolsky, 2000). This idea is strengthened by the reification of metaphor as a design tool (Blackwell, 2006). The concept involves a process in which abstract ideas are made concrete by turning them into generic "tools" in the forms of techniques that designers should apply. This solution signals that a suitable metaphor could be used in presenting abstract information such as haptic feedback as well.

5.2.1 Interface Metaphor

The topic on interface metaphor started since the development of Visicalc in the late 1970's (Wells and Fuerst, 2000). The increase in the work pertaining to this matter becomes noticeable when Apple introduced the desktop metaphor as part of its graphical user interface (GUI). Since then the importance of research pertaining to interface metaphors has prevailed. The concept of metaphor has been widely applied in the context of GUIs. Wells and Fuerst stress that the need to investigate effective metaphor is motivated by the fact that information technology has been utilised widely by various users for different domains of application. The use of metaphor has been employed in a number of problem domains including programming environments (Blackwell, 1998), educational systems (Santos et al, 2004), multimedia systems (Vaananen and Schmidt, 1994) and computer games (Sjostrom, 2002).

The fundamental nature of metaphor is to provide an idea of some unknown thing or concept by illustrating it with something else which is known and which originally has very little to do with it. Metaphor has been used in the user interface to facilitate learning, orientation, and forming and maintaining an understanding of a program. Masden (2000) highlights that metaphor may play two fundamentally different roles depending on whether it is used to express something by building on the similarity between the two referents or to convey something new by emphasising the dissimilarities. Of these two roles, the former has been widely focused on as similarity provides a user with instantaneous knowledge about how to interact with an interface. Learning something that a user has already known could accelerate their learning process. Masden stressed that using metaphor to express the dissimilarity between the two worlds i.e. the real and the computer environment, is as important as using it for similarity purposes. He argued that not only do we want to have a system that resembles a familiar, previous environment but also to benefit from the technology not available in the earlier system. If we reflect on the statement made by Scali et al (2002) in Section 2.3.2, which highlighted that artists would only use computers when the technologies offer advantages over traditional tools, Masden's argument triggers a question of how metaphor could be used in presenting haptic information (i.e. scratchiness, bumpiness, and stickiness identified in Section 3. 4) in a drawing application so that dissimilarity of the two worlds, i.e. real and computer environments, could be established.

Understanding about metaphor theories could assist in determining and justifying suitable metaphorical design for an interface. Wells and Fuerst (2000) provide a brief overview of metaphor theory to support their work. They describe Lakoff and Johnson's (1980) statement, which says that the essence of metaphor is to understand and experience one kind of thing in terms of another. They also outline work reported in Baecker et al's (1995) that discusses metaphors in terms of being some human derived models. Such derivation involves a metaphoric mapping in which the tangible, concrete and recognisable objects from the source domain are transferred to the abstract concepts and/ or processes of the target domain. Wells and Fuerst also note those who have opposed metaphor theory such as Davidson (1979), who argue that metaphors should be treated only for their literal meaning. Lakoff and Johnson counter-argue that the value of metaphor is more than its literal connotation as the distinction arises when one views metaphor as human thought processes. For such occurrence to happen a metaphoric mapping that involves employing suitable metaphors for the context in question is required. This is to facilitate users' understanding of the intended meaning of the metaphors presented on the interface.

Metaphoric mapping in a graphical interface is a process that requires careful consideration so that a correct representation and meaning of a metaphor could be obtained. Every (1999) studied the advantages and disadvantages of "real world" and abstract metaphors. In his context of study, a "real world" metaphor has a real world picture of an object and it is intended to behave "exactly" like its real-world counterpart. On the other hand, abstract metaphors usually have a simpler iconic or stylised appearance and only behave similarly to the actual object in the real world. Abstract metaphor such as Apple's "Desktop Metaphor" is usually in favour because it allows more changes of the interface features and increases of functionality over time, and enables designers to weigh display elements and create more scalable interfaces. Gaver (1995) discusses metaphor and mapping in graphical interfaces by describing the nature of metaphors in both the real world and a computer environment. He states that linguistic metaphors in a computer environment usually highlight similarities between existing entities. The appearance and functionality are two classes of attributes that can be distinguished between the real world and computational world. For computer entities the relation between objects' appearance and underlying functionality is almost entirely arbitrary and must be designed. Such conceptual mapping could be done when a metaphor combines the representation and the system so that the graphics gains the functional attributes of the application. Likewise, this mapping also connects the system with the appearance attributes of the graphics. Gaver suggests that mixed metaphors i.e. names and graphics to be employed. Using both names and graphics allows two models to add and constrain one another since names are capable of strengthening the functionality expressed graphically. This is in agreement with Richards et al (1994) who propose that multiple modalities should be used to enhance the meaning of icons used in a graphical interface. Such usage can help in avoiding ambiguity and difficulty of decoding the metaphor. Richards et al (1994) state that text is the form of augmentation that is most frequently used to support the meaning of an icon. They stress that the importance of metaphors lies in their ability to initiate cognitive transfer from one familiar knowledge domain to another less familiar.

The importance of graphical representation and text when presenting metaphor on an interface is also noted by Blackwell (1998) who investigated metaphor in diagrams. Blackwell describes the concept of "diagram" as forming the middle part of a continuum between two other classes of cognitive artefact: text and pictures. He emphasises that diagrams in user interfaces should be analysed with meaningful interpretation rather than perceiving them as only as a set of objects. In such a case, a diagram needs to be interpreted according to the intention with which it was constructed. Contrary to common belief that diagrams are for assisting with abstract reasoning, Blackwell in his series of experiments confirmed that metaphor in diagrams is to aid memory. Such an effect seems to be more apparent when a user is able to construct his/her own metaphors from the representation on the diagrams. In other words, the metaphor helps users to develop their own understanding and build a mental model about the system. The representation and meaning intended for the system should be correctly transferred to the users so that the user and system models are matched. Blackwell's findings correlate with the study result of Wells and Fuerst (2000), who made a comparison between domain-oriented and frame-oriented interface metaphors for a vacation resort web-based application. The primary difference between these two interfaces was that information in the frame-oriented interface metaphors was organised by abstract categories instead of the resort's physical domain. The study result indicates that a domain-oriented interface caused users to retain more information about the organisation, particularly any domain specific information that is presented in graphical form. The fact that metaphor is useful for mnemonic purposes and there is a need for an appropriate mapping raises the question of what should comprise in a "good" metaphor.

The issues of finding and creating good metaphors in a computer interface are a topic of interest among researchers. Vaananen and Schmidt (1994) urged that a metaphor designer should consider the following metaphor attributes for their design:

i. Real-world metaphors vs. non-real metaphors
ii. Concrete metaphors vs. abstract/ conceptual metaphors
iii. Spatial metaphors vs. time-based metaphors

iv. General metaphors vs. application-dependent metaphors
v. Flexible and composite metaphors vs. rigid metaphors

Vaananen and Schmidt suggest that concrete real-world interface metaphors could help solve the problem of users suffering from confusion and loss of overview when navigating within hyperspace. This could be done by imposing familiar structures and interaction possibilities on the metaphors and visualising them to the users. They claim that concrete real-world metaphors seem to be most appropriate for naïve and casual users. Such metaphors should be considered as most prominent candidates because of their familiarity and attractiveness to most types of users. Santos et al (2004) adopted such a justification in choosing a suitable metaphor for their educational geometry drawing software. Like Vaananen and Schmidt, Santos et al believed that concrete real-world metaphors would be suitable to their target audiences who are apprentices and first time users. The geometry drawing interface has features of four drawing tools, i.e. triangle set, compass, pencil and eraser, which behave almost like their real world counterparts.

A key element in deciding which metaphor attributes are suitable for an application depends on the target users of a system. This decision evolves surrounding the question of whether these users could understand the metaphor. Metaphor must be suitable and familiar to the users in which its design should take advantage of users' previous domain knowledge and experience (Wells and Fuerst, 2000).

The issue of familiarity has been addressed frequently by researchers and became a central theme in research work pertaining to interface metaphors (e.g. Pirhonen et al, 2002; Ryokai et al, 2004; Vaananen and Schmidt, 1994; Santos et al, 2004). Pirhonen et al (2002) used metaphor as an analogy in supporting gesture and non-speech audio as techniques to improve the user interface of a mobile music player. They believed that the success of the design in the study highly depends on the appropriateness of the chosen metaphors. With such an intention in mind, the design and interaction involved metaphor with which the users would be familiar. Pirhonen et al attempted to map the natural gestures a user would make to the interface functions. The key metaphors used in the application were related to the parallel between physical directions and logical order. For example, sweeping across the screen from left to right side indicates selection of the next track of music.

Ryokai et al (2004) describe an implementation of I/O Brush, a new drawing tool aimed at young children to explore colours, textures and movements found in everyday materials by "picking up" and drawing with them. The new physical drawing tool supports the children in transforming concrete and familiar material into abstract representations in visual art projects. Vaananen and Schmidt (1994) and Santos et al (2004) in their work on user interfaces for hypermedia and educational geometry drawing software, respectively, emphasise that familiar representation of the interfaces enables users to immediately understand the functionality of systems.

Familiarity to the users seems to be a key criterion when designing an interface metaphor. In the case of representing haptic information on a drawing interface, the graphical appearance presented should be a metaphor that is familiar to the users. This will enable the users to develop their own mental model of how the underlying functionality of the haptic system feedback should work. An appropriate metaphor should be used so that user and system model could match. So, what should the appearance be like for this haptic drawing interface? What about the underlying functionality i.e. the haptic information associated to such appearance?

5.3 Review of Haptic Interface Design

This section reviews the presentation of haptic information in an interface design. The haptic applications presented in Section 4.4 will be examined whereby they are analysed in terms of how the interfaces are designed for the users and to what extent metaphors have been applied.

In order to systematically present the literature research findings, ideas obtained from Gaver (1995), Vaananen and Schmidt (1994), and Masden (2000) presented in Section 5.2 are applied. In this context, Gaver's argument on metaphoric mapping whereby appearance presented (visual metaphor) signfies the underlying functionality used. Vaananen and Schmidt's classification of metaphor attributes will be used to identify the visual metaphor used in the literature review of Section 4.4. In this case, the "real-world metaphors vs. non-real metaphors" are focused upon. The analysis of the literature review examines the underlying haptic information (haptic metaphor) used in the systems. This involves Masden's idea on the role of metaphor in representing a similar or dissimilar concept. Here, Vaananen and Schmidt's classification "concrete metaphors vs. abstract or conceptual metaphors" are adapted to examine the haptic metaphor used in the literature. The "concrete metaphors" are associated with haptic sensations similar to the real world whereas "abstract or conceptual metaphors" are for sensations dissimilar to 'reality'.

The analysis as described above when applied to the application presented in Section 4.4 has resulted in findings presented in the format of "visual metaphor – haptic metaphor":

5.3.1 Object-based Metaphor – Underlying System Mimics Reality

One of the observations found in the user interface design of the systems presented in Section 4.4 is that a real world object- based interface metaphor has been applied in many applications and such visual appearance has also been associated to the underlying haptic information to be presented to the users. This could be seen in the examples of art-related applications, i.e. DAB, and IMPaSTo; virtual museum applications, i.e. The Museum of Pure Form and the Haptic Museum; and medical applications i.e. HOPS.

In the case of art-related applications, Baxter et al (2001) explain that the DAB system enables users to paint by using a PHANToM haptic device and the space bar on a keyboard. The main component of the user interface in the system is a virtual canvas, which is displayed on the computer screen. The space bar on the keyboard is used as a toggle to show a virtual palette for mixing and brush cleaning or to put the palette aside so that painting could be done directly onto the canvas. On the interface, a wide selection of tools that mimics different types and shapes of brushes used in traditional painting is provided as well. The graphical user interface in DAB which consists of a canvas, a palette and a brush rack is intended to provide a familiar setting conceptually equivalent to a real-world painting environment. Lin et al (2002) stress that an adequate model of the brush is critical to the success of DAB because paintbrushes are often regarded as the most important tools at an artist's disposal. This signals that the underlying haptic information that is associated with the graphical appearance of the interface metaphor is trying to replicate the sensation felt in a real world interaction. However, neither Baxter nor Lin et al directly explain the kind of haptic sensation to be felt with respect to the type of paintbrushes used although they mention the haptic cues obtained as a an overall result from the simulation. It is assumed that such sensation is intended to mimic reality.

An enhancement of the DAB system in terms of its paint model is found in IMPaSTo (Baxter et al, 2004). This new system has the same user interface as DAB with the difference of IMPaSTo allows users to choose between a tablet device (Wacom Intuos2) and a PHANToM. In such as case, IMPaSTo also uses an association of a real world object as its interface metaphor to embed its haptic information. Again, like DAB, no discussion about the type of haptic sensation is mentioned with respect to the paintbrushes used but mimicking reality is the most probable approach for this system.

In the case of DAB and IMPaSTo, the painting systems have been implemented to mimic real world based objects and behaviours, in terms of both the appearance of the paintbrushes on the interface and the haptic sensation felt. Such a design of a user interface is expected because one of the goals of the systems is to support creative process of artists during painting. The visual cues from the virtual brushes on the interface support users to develop their own mental models in understanding how the system works. Such design is exploiting the knowledge transfer of the users based on their previous experience with similar types of interactions.

A parallel finding in terms of mimicking real world appearance and haptic sensations is also seen in the case of virtual museums such as The Museum of Pure Form and the Haptic Museum. Bergamasco et al (2002) describe the goal of the Museum of Pure Form system as being to radically change the way users perceive sculptures, statues or any type of 3D artworks. The system uses concepts from a real-world situation whereby both the procedure and the physical site where the interaction occurs are replicated. The Museum of Pure Form provides two haptic devices for the users to interact with the artefacts, which are an exoskeleton device and a desktop device, developed inhouse. Due to the nature of the system, real world interface metaphors have been used in the design in which representations of selected artefacts in the real museum are graphically rendered on the interface. Such graphic appearances enable the users to know the sculpture and which area of this object is being touched. These visual cues indicate the haptic information that users may receive from their haptic exploration. As Bergamasco stressed that the underlying idea behind the system refers mainly to the haptic perception, i.e. the capability of perceiving 3D object features such as shape, hardness and temperature, it could be concluded that the haptic information presented in the system tries to replicate its real-world counterpart.

Another example in the area of virtual museums is the Haptic Museum project presented in McLaughlin et al (2000), which includes a haptic exhibition on early photographic processes for the Fisher Gallery. The objects consist of the earliest forms of photography, which are daguerreotypes, ambrotypes and tintypes in which all of these items have very subtle tactile qualities. Like The Museum of Pure Form, the virtual artefacts presented on the user interface take the real world form in terms of their appearances. The haptic information associated with the objects is embedded within this graphical representation. For haptic interactions, the PHANToM and CyberGrasp are used in the system. It is not mentioned whether the underlying haptic sensation of the objects attempts to mimic the real world situation. However, due to the nature of the system perhaps it is safe to make such an assumption.

From the findings in the cases of the Museum of Pure Form and the Haptic Museum, the fact that these systems attempt to allow users to feel the actual tactile sensation of the objects in the real world imposes that a virtual object should look and feel similar to its actual physical counterpart. Likewise, the purpose of the Glasgow Horse Ovary Palpation Simulator (HOPS) application, which is meant to assist medical students in their training, determines the type of haptic sensation a system should have. The HOPS system was developed to provide training to the veterinary students during their trainings (Crossan et al, 2002). The user interface of the system consists of an abstract graphical representation of a left and right ovary, a spherical follicle (a thin walled, soft partially submerged object on an ovary's surface) on one of the ovaries. These graphical representations provide a visual cue to the users on the kind of tactile sensation to expect when interacting with a model using a PHANToM. Such expectation is developed based on the users' interactions in the real world. In the case of this simulator, the underlying functionalities of the haptic information are mirrored through the visual appearance of the objects on the interface. This haptic sensation is mimicking the actual tactile experience in the real world interactions. In other words, this system uses an abstract representation of a real world object on the interface whose underlying haptic information mimics the real world sensation.

5.3.2 Object-based Metaphor – Creative Underlying System

Another observation made from the applications in Section 4.4 is a visual metaphor that has an abstract representation of a real world object but an underlying haptic feature that is creative. Applications for blind users, i.e. haptic graphs, Senses in Touch II, and Submarines; art-related application, i.e. Dynasculpt; and a haptic weather system are among the examples of systems that embed and provide haptic information which may not resemble any specific real world tactile experience to the users.

In presenting haptic information on a user interface for visually impaired people, Yu et al (2001) embedded the haptic information into a polygon that represents the graphs on the user interface. Multiple lines on a graph are being represented by using different polygons in which each is assigned with a different friction surface to distinguish them from one another. Such visual appearance is not important due to the nature of the application. Also, it is predicted that the underlying haptic information associated with this visual cue has no resemblance to any particular sensation in the real world interaction.

Yu et al (2003) extended their work on representing haptic graphs to visually impaired people via the Web. The focus of the study was to assist blind people to create virtual graphs. The haptic device that has been used in this study involves a WingMan FF mouse. The application developed allows the users to perform line drawings to create a graph. The user interface of the application has a simple layout, which consists of a grid with 14 rows and 25 columns. Yu at al explain that the intention is to replicate the graph paper that a sighted person would use. This signals that a real world object interface metaphor is used in the computer design. The haptic information is embedded into these grids so that a user could count the rows and columns based on the force feedback from the mouse to assist a drawing interaction. Yu et al describe the force feedback to represent the line graph as the grid effect.

On the other hand bar and pie charts use the enclosure effects, which are defined as areas bounded by force walls. Such haptic feedback includes elliptical and rectangular effects. As an example, a magnetic force is being applied onto the pie edge in the application to indicate the shape of a pie chart. This haptic effect shows that the underlying haptic information associated with the appearance of the interface is very creative and does not follow a real world interaction.

Another example of an application for blind users is described by Brewster (2005) who presents a research work on a haptic museum exhibit, called Senses in Touch II. This exhibit is particularly aimed at visually impaired school children. A Wingman haptic mouse is used for the interaction and to feel the force feedback. Objects that were included on the interface are coins, engraved Egyptian hieroglyphics and the cast of a dinosaur footprint. The user interface of the exhibit consists of a menu containing a set of objects that are available to be felt which is located on the left hand side of the screen. The selected object in this menu is being associated with its detail image presented on the right hand side of the interface. Like the haptic virtual graphs presented by Yu et al (2002; 2003), these real world interface metaphors are associated with the underlying haptic information in a very creative manner as the tactile sensation may not represent the actual real world experience.

In addition to the examples for blind users, Sjostrom (2002) in his PhD thesis presents various types of haptic demo applications used to construct his set of guidelines for non-visual haptic interaction designs. These applications have been tested with blind and sighted users. Among the goals of his research work is investigating how graphical user interfaces can be made accessible to blind persons using virtual haptics. The "Submarines" application is a haptic version of a well-known battleship game. The ordinary pen-and-paper based battleship game consists of a 10 x 10 coordinates system meant for assisting students' learning. It was indicated in the reported work that the user interface of the system replicates the actual grid of its real world counterpart. The squares on the interface are being associated to one of these states of haptic feedback simulated using a PHANToM: calm waves; no waves; vibration; small waves. Despite using a real world based interface metaphors for the graphical appearance, the underlying haptic information is presented creatively and not following any real world interactions.

Presenting haptic sensations in a creative manner corresponds to Masden (2000) who stated that in designing a system we should also try to benefit from the power of the technology and provide opportunities not available in the real world environment.

In the case of a haptic weather system, Omata et al (2005) used a real world graphical representation of objects in their interface. These representations signal the use of a real world interface metaphor in the design. This is expected due to the nature of the application in question. However, the underlying haptic information embedded within these visual cues is based on the designers' creativity. In the application, a wind force is represented by a change in frequency of vibration while a direction of the wind is simulated using a constant reactive force.

5.3.3 Object-based Metaphor – Underlying System Unknown

Even though some of the applications discussed in Section 4.4 have involved some elements of an interface metaphor whose visual appearance represents real world based objects, the feeling of haptic sensation embedded has not been discussed. This is mainly due to haptic perception not being the main focus of those studies. Such observation is found in most of the applications that involve technical issues of haptic research. An example of these systems presented according to various groupings is as follows: art-related applications, i.e. InTouch, ArtNova, Haptic Painting and Decoration, Chinese Painting and Calligraphy, and Virtual Sculptor; medical applications, i.e. Remote Ultrasound Examination, Simulation of Temporal Bone Surgery, and Simulation of Complex Surgical Procedures.

The first example of art-related applications is InTouch, which has been described as being useful for a geometric modeller as well as a 3D paint program (Gregory et al, 2000). This system combines visual display and force feedback in order to allow users to naturally create complex forms and patterns. Its user interface consists of a 2D menu drawn over the edge of a stereo projected 3D scene. This menu contains the model being worked on, along with a graphical representation of the tool being used. For 3D painting, the user can interactively choose the colour, saturation, and luminance of the brush stroke as well as its radius and falloff by naturally dragging in a 2D canvas. These painting facilities are represented on the menu selection as images of a paintbrush and a colour palette. In this case a representation of an abstract object in the real world is used as a metaphor for the interface design. Users could feel the tactile sensation of the surface model at all times using the PHANToM haptic device. However, no further discussion is made about the underlying haptic information of the system in terms of the kind of sensation felt by the users.

The second art-related example is ArtNova whose ability includes supporting a 3D painting of solid colour strokes and textures on arbitrary polygonal meshes (Lin et al, 2002). On its graphic user interface, a user could see the model being edited, the tool being used and a menu that can be operated using either a PHANToM or a mouse. A different painting tool is assigned to each type of model manipulation. As an example, a mechanical claw is used for moving an object, a paintbrush for painting and a suction cup for deforming an object. During the process of editing a surface, a user can feel a resisting force and see the surface deform. The edit resolution is presented to the user as a "bump size" which is displayed on the screen separate from the tools menu option. This textual cue indicates the underlying physical functionality of the haptic information to be perceived but no discussion is made on the type of sensation to be felt. On the tool menu, a continuous colour picker, sliders for brush width and decrease of paint opacity and choice of textures for painting are provided. These graphical representations use the analogy of the actual objects in their real world counterparts as the interface metaphors.

The third example of art-related application is the Virtual Sculptor, a real-time interactive modelling system with force feedback (Lu et al, 2002). The system has been described as having several basic tools for creating models: a carving tool that cuts material, a filling tool that stuffs material, and a painting tool that paints colour on the surface of a model. It provides users with simple shapes such as sphere, ellipsoid, cylinder and box to be manipulated in order to create various models. All these tools are displayed on a 2D menu of the user interface. These graphical appearances on the interface take the form of an abstract representation of real-world based objects. The haptic information has been embedded into these visual cues although it is not mentioned in the publication about the haptic sensation to be felt for the sculpting process.

Other examples of art-related applications could be seen in an initial model of haptic editing of decoration and material properties as reported in Kim et al (2003). They do not mention the implementation of the user interface of the prototype. This is expected because their focus of research is on the haptic rendering technique rather than the interface design. Kim et al only present the screen shots of the finished products of the decoration work. A similar situation is found in the case of Yeh et al (2002) in their Chinese Painting and Calligraphy system. Like Kim and Yeh et al's haptic designs, the user interface of the Virtual Sketching prototype as presented in Wall et al (2002) is not described in the reported work. The prototype, which is developed as part of the Tacitus project is meant to test the impact of specific haptic support in assisting artists to transfer their ideas to a computer environment.

In the case of medical applications, the remote ultrasound examination project whose aim is to provide an accurate solution to practice expert examination in distant geographic areas (Guerraz et al, 2002) provides an example of unknown underlying haptic sensation. Due to the nature of the study, not much has been reported specifically on the user interface design except for a screen snap shot example of a 3D model showing a deformable abdomen of a distant patient. This visual representation indicates that a real world based interface metaphor is used in the interface design. However, it has not been mentioned about the kind of haptic sensation associated to this graphical image when one interacts with the model using a PHANToM. Like Guerraz et al's approach in presenting a user interface design of a system, Morris et al (2004), reporting a simulation of temporal bone surgery, note the visual representation of the bone displayed on the interface. This signals that a real world based object has been used in presenting the underlying information on the interface but no discussion is provided with respect to the associated haptic sensation. A similar finding as described about Morris et al in terms of the user interface is also noted in Sewell et al's (2004) work on a mastoidectomy training system.

5.3.4 Textual Metaphor – Underlying System Unknown

One way haptic information has been presented with respect to the user interface is by including some related textual representations to control the underlying features of the system. This could be found in the Fetouch system in which various buttons and slider bars containing textual descriptions of features for manipulating the visual image of a virtual object and its haptic properties are provided. The system was developed to allow mothers to interact with a model of the fetus they are carrying. Torre et al (2004) stated that the system has not been designed with medical diagnosis in gynecology and obstetrics as their primary focus. So in this case the user interface that includes a 3D fetal model whose surface is enhanced with various effects, such as compliance, heart beat and skin texture is not physically based on real world data. This implies that the features associated with the model are just an abstract representation of a real world situation. Unlike HOPS, for which the underlying haptic information tries to be similar to the real world, Fetouch system does not share this characteristic as it is just based on the designers' creativity. On the graphical user interface some textual information to control the systems has been presented such as "Object opacity", "proxy radius", "OBB Tree", "OBB S/W", "OBB Tree opacity" and "Number of triangle" which are all associated with the 3D model. Likewise, textual information labelled as "Orientation", "SCP", "Proxy", "Velocity", "Force", "Average update", "Damping factor" and "Elastic factor" are shown to control the force feedback of the PHANToM.

In the case of Fetouch, a combination of visual appearance that represents real world based objects and textual information of the underlying features has been used as interface metaphors in an application. A manipulation that involves the haptic features in the system allows a user to change some parts of the physical parameters of the haptic device. A similar pattern is found in Texture Touch (Guerraz et al, 2003) and ArtNova (Foskey et al, 2002) whereby textual information has been used as a metaphor for the interface design.

In Texture Touch, a simple application used in a pilot experiment of using physical parameters obtained from a PHANToM to enhance an evaluation activity, the examination of its user interface could benefit our analysis. Texture Touch allows painting to be done on a flat surface in which the users could feel the haptic feedback of the line drawn during and after the process. Drawing a different line width is made possible by choosing a different graphical texture width, which is presented as a button on the user interface labelled "texture width". Along with this feature, there are other buttons that are labelled "stiffness" and "texture depth". However, these interface metaphors have not been mentioned nor discussed in the reported work. Also, the usage of the textual information on the buttons in the Texture Touch application is not clear, as these texts have not been described in the reported work. If the interface metaphors are meant for conveying the haptic information similar to the text "bump size" in ArtNova users interface presented in Section 5.3.3, it is still not known whether the tactile sensation should feel similar to drawing in the real world counterpart or not.

5.3.5 Unknown Metaphor – Creative Underlying System

One observation found when studying the interface designs in Section 4.4 is that in the applications discussed, the interface metaphor is unknown but the underlying haptic system is creative. For example, "Paint with Your Fingers", an application noted in Sjostrom's (2002) work, presents underlying haptic information that is very intuitive. In the application, users are able to choose a colour from a palette using a PHANToM and paint it on the interface. They could feel a different haptic sensation during interaction as it has been embedded within each colour. However, the appearance of the user interface has not been explained. So no conclusion could be made in terms of whether a real world interface metaphor is involved or not when presenting the haptic information.

In the case of Snibbe (1998) in his Dynasculpt, despite not having a metaphor that is visually representing a real world object, the underlying haptic information has been presented creatively as well. Dynasculpt is an example of a sculpting prototype that does not follow any interactions or behaviours in the real world. This characteristic is motivated from the fact that the majority of work pertaining to haptic modelling has concentrated on a simulation of real-world objects. This situation has led towards a phenomenon in which users tend to compare the computer system in question with its real world counterpart. Snibbe et al attempted to move away from this common practice in order to provide experiences based in dynamic systems but not directly reflecting real-world phenomena to support creative expression. Dynasculpt allows 3D sculpting by attaching a sprung virtual mass to the PHANToM position and creating a ribbon or tube along the path taken by the mass through space. Snibbe et al, however, do not describe the user interface in the article, so not much could be deduced on whether any interface metaphors are involved in the prototype despite the fact that the underlying haptic feedback of the system does not mimic any particular interactions in a real world situation. The interface design concept used in Dynasculpt is in contrast with the art-related applications discussed in Section 4.3.1 such as DAB and IMPaSTo, which attempt to be as realistic as possible to those in the real world counterparts.

5.3.6 All Others

This section presents all other findings in terms of presenting haptic information, which involves metaphor in interface design. In much of Sjostrom's (2002) work that involves haptic games such as "The Memory House" and educational applications such as "Line Drawings" and "Mathematical Graphs", both appearance on the user interface and the associated underlying haptic information are creative and do not mimic any particular real world interaction. In terms of the interface metaphor, this feature is also found in shared virtual environment applications such as "Ring on a Wire" game (Basdogan et al, 2000). Like the gaming application in Sjostrom's studies, the interface metaphors used are an abstract representation of some geometric objects and do not replicate any real world entities. The haptic information embedded in these objects is not noted in terms of the kind of tactile sensation as it was beyond their scope of study.

Unlike these applications discussed in Sections 4.3.1, 4.3.2, and 4.3.4, which involve haptic elements in the research, there are also systems that only use the PHANToM haptic device as a mode for interaction purposes without particularly focusing on any issues in haptics. These could be found in the art-related haptic applications presented in Johnson et al (1999), Tano et al (2004), and Chu and Tai (2002). Johnson et al explain that their user interface design of painting textures system contains a toolbar (for paint selections), a paint ball (representing the PHANToM cursor on the computer screen), a model painting space, and an optional texture display. The system allows users to use the PHANToM to access all these painting features. On the toolbar selection, a colour block is provided for the users to choose the colour to be textured on the model. A few blank boxes are also provided at the bottom of the toolbar for mixed colours that need to be saved. The radius of the paint ball will determine the size of the texture to be painted on the model. The toolbar provides an option to resize this paint ball by either stretching or shrinking the radius of the ball. Even though all the painting interactions can be done using a PHANToM, the haptic feedback is not the main concern of Johnson et al's study. In this case the graphical appearance on the tool bar does not actually signify any underlying haptic functionality of the system. It could be surmised that an interface metaphor that follows a real-world based object has been used although not representing any haptic information of the system.

In the case of Tano et al, they included a design of 3D sketching using a PHANToM as a medium of user interactions in their research work. Tano et al propose having a user interface that uses metaphors of "shadow" and "hand mirror" of the sketches made. These graphical images become the main elements on the interface design. Like Johnson et al, this 3D sketching is not focusing on the haptic sensation; thus, the appearance on the interface does not represent any underlying haptic information of the system.

Like to Tano el al, in terms of the role of the haptic device in the application developed, Chu and Tai present a 3D brush model for physically based 3D painting in which one of the modes of interaction is using a PHANToM. Their work attempted to model only the physical properties that are necessary for producing realistic visual results. They focused on reproducing features of Chinese brushes that are important in the artistic sense. In the reported work, the section that describes the user interface mentions the significance of the visual feedback of the brush shape during a painting process. The interface shows a perspective view of a 3D painting scene, and a brush being rendered with lighting and shadows to aid visualisation. This has indirectly indicated that a real world based interface metaphor is being used in the system. Like Johnson and Tano et al, the PHANToM haptic device is mainly used for interaction purposes and not for haptic feedback. In this case, there is no relationship that can be made between the visual interface metaphor and the underlying haptic information of the system.

5.4 Learning from Graphical Systems

The literature findings in Section 5.3 have presented various ways others have applied metaphors in their haptic designs. In order to apply these results to find suitable designs for a haptic drawing application, the way a commercially graphical system presents one of its abstract information in an interface design is examined. This area is chosen because it provides a simple example of how reification of metaphor as suggested by Blackwell (2006) could be demonstrated. The purpose is to replicate similar ideas to a haptic drawing interface so that users are familiar with the representation used in the proposed design.

5.4.1 The Case of Editing Colour in Microsoft Draw

When designing a graphic interface for a drawing application in which the tactile feedback is the key question to be investigated, it is necessary to find a suitable metaphor that could embed such haptic information. This is to facilitate users' interaction when interacting with the system. An initial step towards finding a suitable metaphor is by examining the way an abstract concept of information is presented metaphorically in a generic drawing application. As an example, consider information about colour on the Microsoft Draw interface. This system is chosen for this purpose because it is a common drawing application on most computers. An example of such an interface is presented in Figure 5-1.

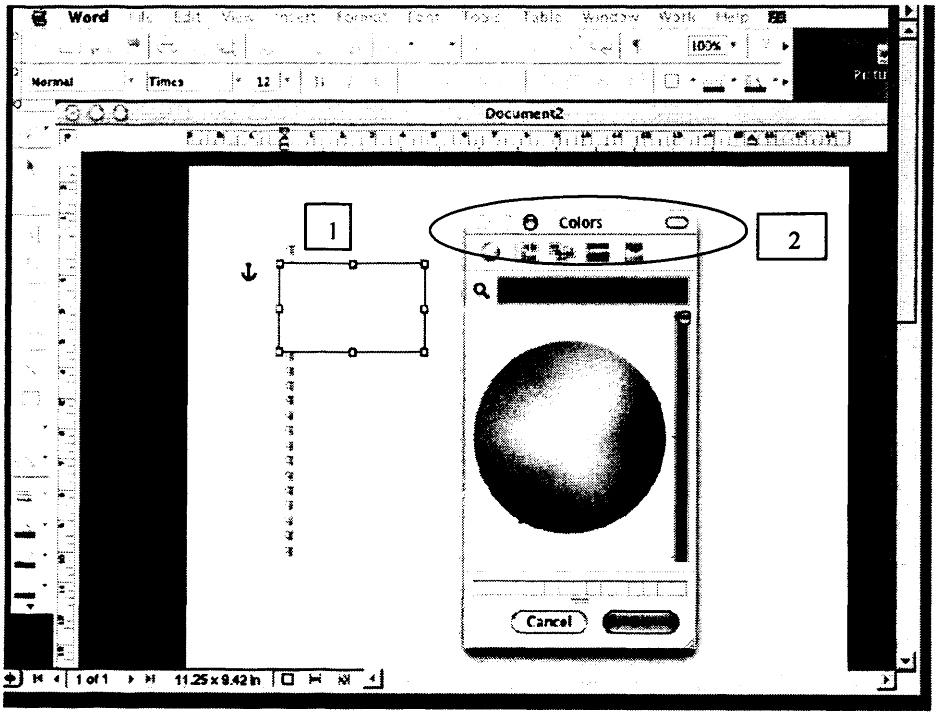


FIGURE 5-1: COLOUR OPTIONS OF MICROSOFT DRAW (ON MACINTOSH)

In Figure 5-1, suppose we have a situation in which we want to change the colour of the rectangle drawn (marked as '1'). By activating the pop-up windows (as shown on the right of the rectangle), several options for changing the colour are provided. The options, which have been circled and marked as '2', consist of "Color wheel", "Color sliders", "Color palettes", "Image palettes", and "Crayons". Of these five choices, the "Crayons", which uses images of real-world objects as its visual representation and the "Color sliders", which has the colour elements of hue, saturation, and brightness will be examined. They are chosen rather than the rest because "Crayons" includes a real-world object analogy and "Color sliders" involves another type of interface metaphor as noted in the study findings presented in Section 5.3. The "Crayons" option is also chosen because it correlates with the pen tools used in the study presented in Chapter 3. These options are shown in Figure 5-2 and 5-3, respectively.

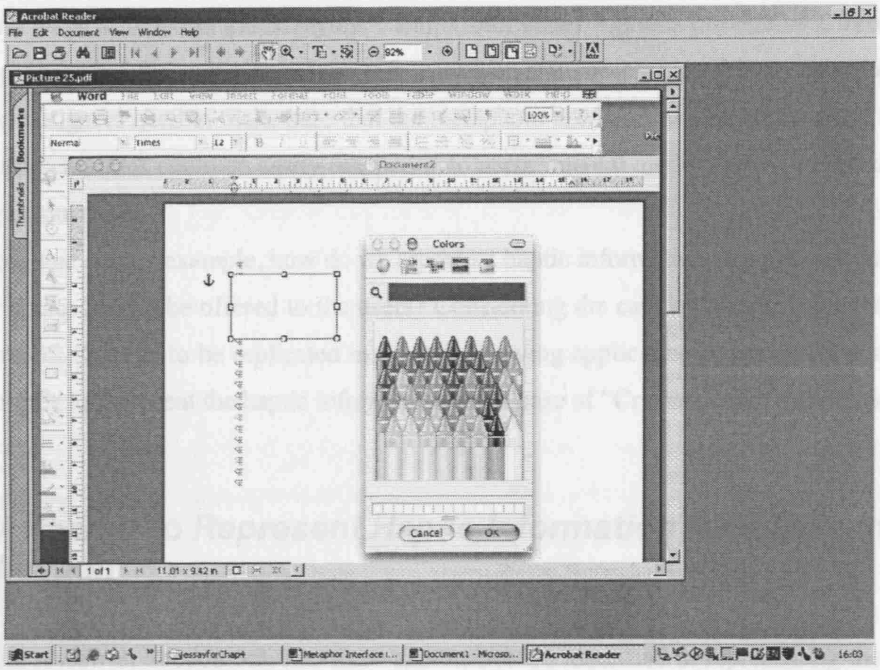


FIGURE 5-2: "CRAYONS" OPTIONS OF MICROSOFT DRAW (ON MACINTOSH)

In the case of "Crayons", we could immediately choose a colour we want by selecting the coloured crayon we wish to have that is visible on the interface of Figure 5-2. Likewise, dragging the slider bars of the respective elements shown in Figure 5-3 could edit the colour of the rectangle.

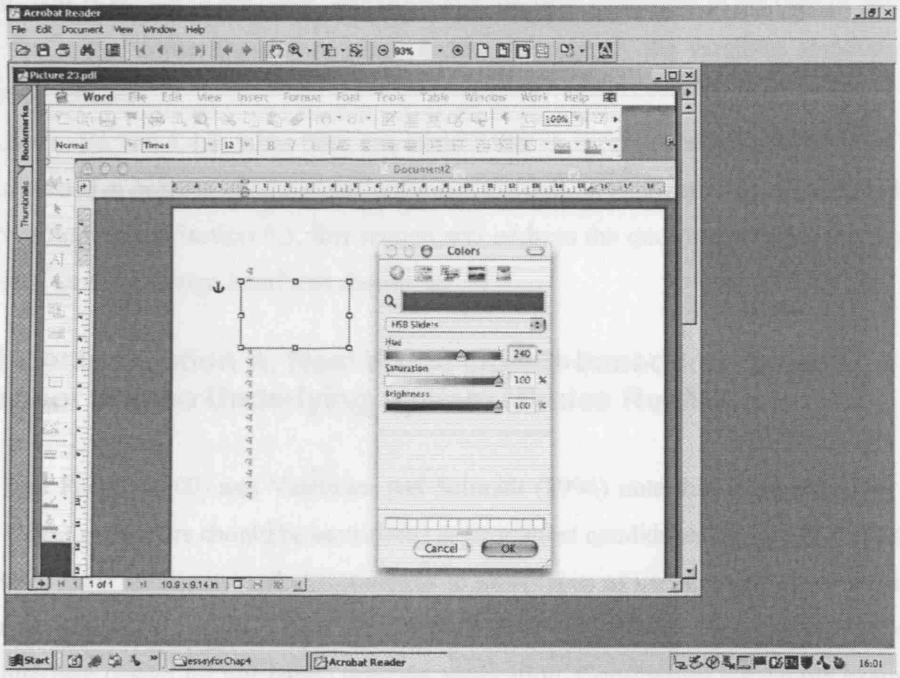


FIGURE 5-3: "COLOR SLIDER" OPTIONS OF MICROSOFT DRAW (ON MACINTOSH)

Both ways as noted in the "Crayons", and "Color slider" options provide us a freedom to perform changing the material colour task based on our preference. When designing both options, designers need to make sure that the metaphors used are familiar to the users so that such representations could be easily mapped onto users' mental model; hence, facilitating the editing colour task.

From this simple example, how do we represent haptic information in a drawing interface so that choices could be offered to the users? Considering the case of editing colour material in Microsoft Draw is to be replicated in a haptic drawing application, what would a suitable metaphor be to represent the haptic information in the case of "Crayons" and "Color slider"?

5.5 Metaphor to Represent Haptic Information for a Drawing Application

From the review in Section 5.3, two main approaches are identified in representing the visual appearance of an interface metaphor. The first is using a real world based object as its metaphor on the interface. This corresponds to the simple example from Microsoft Draw, which has the "Crayon" as an interface metaphor. The visual appearance is used to prompt a user to conceptualise and build their own metaphor in order to understand the underlying functionality of the system (Blackwell, 1998). The second approach provides some textual descriptions on the user interface as a metaphor to convey the underlying information of the system. This is similar to the other alternative that has been examined in the case of Microsoft Draw that is the "Slider Option" in which textual cues signify the variables associated with colour information.

Also, in Section 4.4.3, it has been emphasised that an appropriate representation of haptic cues is needed in order to obtain users acceptance towards an application system. By using the literature findings in Section 5.3, this section will address the question of what the proposed options in terms of design interfaces should be.

5.5.1 Design Option A: Real World Object-based Interface Metaphor Whose Underlying System Mimics Reality

Wells and Fuerst (2000) and Vaananen and Schmidt (1994) note that a concrete real world based object metaphors should be considered as prominent candidates for interface metaphors because of their familiarity and attractiveness to most types of users, especially for first time and casual users of a system. This statement may direct us towards proposing the first option of an interface design for our haptic drawing application. Considering the simple example of editing colour material in Microsoft Draw, in which the "Crayon" appearance is used on the interface, may also provide a hint to our new design. In the case of a haptic drawing application, a potential metaphor should have an appearance that provides a cue to the users of what the haptic feedback may feel like. Such appearance should also reflect the chosen PHANToM haptic device, which has a physical form that resembles a pen-tool, as specified in Section 4.5.1. These criteria suggest that the tools commonly used in a drawing activity such as pen-like tools and papers could be among the possible candidates to be considered as interface metaphors in the design option.

In representing the real world based objects metaphors, diagrams as described by Blackwell (1998) could be used whereby the appearance on the interface may involve representation of some pictures and texts that are associated to the objects in question. The familiarity of these representations to the users may lead towards a mental model of the kind of haptic feedback expected from the drawing tools. This is in parallel to Gaver's (1995) statement, which noted that graphical appearance signifies the underlying functionality of the system. In the case of our haptic drawing interface, the drawing tools metaphors should be able to convey the information about haptic sensation of a drawing interaction. The fact that the appearance of the metaphor attempts to represent a real-world situation indicates that similar haptic information to that which occurs in a real-world drawing interaction should be presented. This proposal corresponds to Masden (2000) who notes the two roles of interface metaphor, one of which is to represent something similar in the computer system to match those available in its real-world counterpart. In other words, in the case of the first interface design option, the underlying functionality of the system should comprise the haptic information that mimics a real world drawing interaction.

Having established the criteria for the first design option, the next question is what alternative would satisfy user's needs? Gaver (1995) emphasises that an interface metaphor acts to combine a representation and its system so that the graphics gain the functional attributes of the application, and similarly this system benefits from the appearance attributes of the graphics. These two-way actions suggest that using the haptic information as presented in the first design option may be able to determine the graphical appearance of the metaphor. In choosing an interface metaphor, familiarity is a key element to be taken into consideration, as it may lead to a correct mapping between a user and system models. So, what is this haptic information that is familiar to a target user of a drawing system?

5.5.2 Design Option B: Textual Interface Metaphor That Underlying Haptic System is Creative

Nakakoji and Yamamoto (2003) consider sketching (drawing) as a representation of an object. They state that the act of holding a drawing tool, i.e. pen or pencil, and moving this tool while pushing its lead to obtain a mark on a piece of paper is an interaction. In such a case a drawing interaction can be equated to an object that should contain the haptic information in question. In Section 4.5.2, it was proposed that a simple rendering technique using the parameters provided mainly by the PHANToM and manipulating the frequencies and amplitudes of the sine waves to generate haptic textures, as used by McGee et al (2001), should be adopted in this research project. The force feedback rendered will provide the haptic information, which could be felt when an active exploration is performed on the surface texture. One suggestion could be having all these underlying parameters shown to the users so that they could see the "appearance" of the interface metaphor. If this is the case, parameters such as "dynamic and static frictions", "damping and spring factors", "frequencies" and "amplitudes" that will be involved in haptic rendering may be made available to the users. The question is how familiar are these terminologies to the target users? The danger of having this set of terminologies on an interface design is that we are assuming that the users are familiar with the relationships among the underlying haptic parameters. In other words, users are expected to know how the PHANToM haptic device works. This is not an ideal situation because the users have to adapt to the technology. In finding a suitable interface metaphor, a balance is needed between the physical haptic underlying parameters with the haptic information perceived during a drawing interaction.

In Section 2.2.2, it was noted that people usually describe the objects they feel in three different ways i.e. cognitive, perceptual and physical (Minsky, 1995). By the way we explain haptic sensations the dimension cues of scratchiness, bumpiness, and stickiness presented in the study in Chapter 3 have evolved. Based on this study, these are the haptic sensations familiar to artists in a drawing interaction. The sensations may be made "visible" to the target users in the proposed alternative design option. Referring to the example of the "Color sliders" design option in Microsoft Draw, the terms "scratchiness", "bumpiness", and "stickiness" could be simply represented as a visual metaphor on the interface. Also, these variable names seem to be less technical than the physical underlying parameters suggested earlier.

The decision to have a group of variable names that consist of haptic sensations for an alternative design option implies that diagrams will be involved in the appearance of the metaphor (Blackwell, 1998). The textual information that appears on the interface should provide cues for the underlying haptic functionality that needs to be presented. The fact that such appearance does not represent any intended real world based objects, i.e. drawing tools in the real world, suggests that the haptic information may not necessarily follow any particular haptic sensation as when interacting using any drawing implements in the real world. This would also be an opportunity to apply the other role of metaphor as noted by Masden (2000), which is to represent dissimilarity. This could also address the issue raised by Scali et al (2002) presented in Section 2.3.2, which suggests to designers of the possibility that artists may not use the computer if no additional functionalities are available to support their artwork. Considering such haptic information for the alternative interface design option would enable us to make a comparison of users' preference in terms of the tactile sensation for a drawing interaction in a computer environment. Such comparison can only be performed once these two haptic design alternatives have been implemented in a drawing prototype.

5.6 Chapter Summary

This chapter has proposed two types of haptic interface designs that will be explored in this research thesis. These conceptual designs are formulated and based on the concept of metaphors and literature findings from how others used metaphors in their system designs. The use of metaphor to represent haptic information in a drawing design is motivated by Blackwell's (2006) argument on reification of metaphor, i.e. making abstract concepts concrete.

The literature has revealed that real world object-based metaphor whose underlying haptic system either mimics reality or is creative, is one of the approaches used in representing haptic information in a design. Another approach is by using textual descriptions of the haptic sensations. Most of the studies reported, did not address the issue of applying the concept of metaphor in their design, as it was not the focus of the research.

As a guide to decide a way to represent haptic information, an example in Microsoft Draw, a graphical drawing system, was presented in an interface. The "Crayon" and "Slider" options were chosen as the basis for involving the real world object analogy and the textual descriptions used, respectively. Using these two design selections in presenting an abstract concept, and the literature findings, the two haptic design options proposed are: (Design Option A:) an interface design whose metaphor has real world object-based that underlying haptic mimics reality; and (Design Option B:) a textual description interface metaphor with creative haptic feedback. This leads to the question of how do we implement these concepts in a haptic drawing prototype?

Chapter 6 Simulating the Haptic Cues

6.1 Introduction

The aim of this chapter is to demonstrate how the set of haptic dimension cues presented in Chapter 3 can be represented on the two types of interfaces proposed in Chapter 5. The integration is motivated from the research findings highlighted in Chapter 4 which noted that even a simple texture rendering technique that manipulates the parameters provided by PHANToM could simulate haptic feedback realistic enough for the environment under study. This chapter presents the second part of the practical work that aims to address the research question in Section 1.2 of the thesis which is: *Question 3: How do we integrate the haptic features identified in an interface?*

The chapter outlines a brief conceptual design and some general requirements of the prototype, called HapticDraw. It suggests an idea of how the prototype should be designed. This leads to describing the implementation of the prototype, which includes the specification of the hardware and software used, and how the graphics and haptics components are to be developed. The first design layout provided in the earlier stage of the development takes the form of a real world object-based interface metaphor whose underlying haptic system mimics reality. This is intended to exploit users experience and perception when interacting in the real world as presented in the literature review sections. The development process also includes several formative evaluations, the feedback from which is used to improve the interface.

The chapter progresses with a description of the alternative interface design implementation for which haptic feedback is derived from those in the first design. This interface involves a metaphor that provides a textual description of the haptic feedback which creates an underlying system that is intuitive and creative. Both the first interface design and its alternative option represent the variable haptic interfaces as stated in Chapter 1. The implementation stage ends with the preparation of a fixed haptic interface design to be used as a comparison study with the variable haptic interfaces in this research project. Towards the end of the chapter a section is dedicated to discussing the strengths and limitations of the implementation.

6.2 Conceptual Design and Rationale

The drawing process in the real world environment provides rich information in terms of the users' haptic experience during the interaction. The tactile feedback received is an important element in this process. The collective opinion from a group of traditional artists during a drawing activity (Chapter 3) suggested that an interaction using various types of pen-like tools on different types of papers produces a series of different tactile sensations. From a library of this real world interaction, the tactile experience when drawing, for example using a 2B pencil on rough paper, includes the feeling of softness, smoothness, stiffness and roughness, and scratchiness and roughness. Ideally, this tactile sensation should be experienced when interacting in its virtual world counterpart. The question is how do we transfer this instance of real world interaction, which contains users' subjective tactile experience in a drawing prototype?

To re-emphasise points made in Section 5.5.2, sketching (drawing) is considered as a representation of an object. The act of holding a drawing tool, i.e. pen or pencil, and moving this tool while pushing its point tip to obtain a mark on a piece of paper is an interaction. In view of this, the main elements to be focused on during a haptic interaction in the proposed prototype are the tip of the pen-like tool, the drawing surface, and the pressure applied on the virtual surface. The prototype should provide users with a tactile experience during their drawing interaction on the interface. In other words, it should follow a similar analogy of drawing in the real world in terms of enabling users to draw on a paper surface and feel the tactile sensation of the interaction.

As discussed in Chapter 4, Yu et al (2003) noted that force perception is a difficult matter so it is important to provide options in terms of interface representation for the users to choose. Sections 5.5.1 and 5.5.2 have presented two design options to represent haptic sensation, namely, (Design Option A): an interface design whose metaphor is based on real world objects whose haptics mimic reality, and (Design Option B): a textual description interface metaphor with creative haptic feedback. Should these design options are to be adopted for a drawing application, how would they be on a user interface?

A simple solution could be to replicate a basic design layout that is common to most users such as Microsoft Draw. By adapting its design concept, two different interface layouts could be implemented. Relating the two haptic design options proposed with the study findings presented in Chapter 3, a summary of conceptual ideas for the design interface is:

(i) Design Option A – Pen tools and paper type metaphor whose underlying haptic sensation mimics reality

For this interface design, users are able to choose various pen tools and papers in which the haptic feedback felt should reflect each combination selected. In this case, the underlying haptic sensation that mimics reality is a composition of haptic feedback from the scratchiness, bumpiness, and stickiness.

(ii) Design Option B – Abstract haptic parameters metaphor that reflects creative haptic sensation

For this design, users are able to manipulate the haptic feedback directly on the interface from the dimension cues provided. As suggested in Section 5.5.2, the words "scratchiness", "bumpiness", and "stickiness" should be made visible on the interface, and the level of haptic sensation provided for user-controlled purposes.

A simple way to represent this degree of haptic sensation is by involving minimum and maximum feedback to the users. Holmes et al (1998) when investigating texture roughness used the quantitative measurements, maximum and minimum. With this information the parameters e.g. 'low', 'medium', and 'high' scratchiness could be implemented on the interface to represent the degree of haptic cue in question.

With regard to the underlying haptic feedback for this interface, the dataset used in implementing the haptic sensation for Design Option A is used to assist in determining the minimum and maximum values for Design Option B.

6.2.1 Overview of the Implementation

It is envisaged that the HapticDraw prototype should provide similar tactile experience from drawing or sketching activities in the real world. To assist in achieving this vision, the PHANToM has been chosen to simulate the haptic effect since this device is available in the department and it is also capable of providing satisfactory feedback during an interaction. The choice of this equipment has indirectly pre-determined the selection of computer language and graphical interface toolkit used.

In general HapticDraw should enable users to make marks or lines using the PHANToM. This simple capability was intended because it features mostly in the previous literature and also because it is an elementary operation in traditional drawing (Rosand, 2002). With this functionality, users can perform line sketching or drawing, as the activity is both simple to do and also perhaps the most fundamental and familiar interaction in a drawing application.

The HapticDraw prototype was written in C++ using Microsoft Visual C++ Version 6 under Windows 2000. In order to have the same look and feel as a typical application running on a Microsoft platform, the standard Microsoft Foundation Classes were used to generate the graphical user interface. While the graphics objects in the environment were created using the OpenGL API, the haptic codes was developed using the GHOST API supplied by SensAble Technologies in order to make PHANToM haptic device works.

System Architecture

The main idea of developing the HapticDraw prototype is to enable users to feel the haptic cues during their interactions (i.e. when drawing activities take place). In order to capture this view and for discussion purpose, a simplified representation of the system architecture for HapticDraw prototype is presented in Figure 6-1.

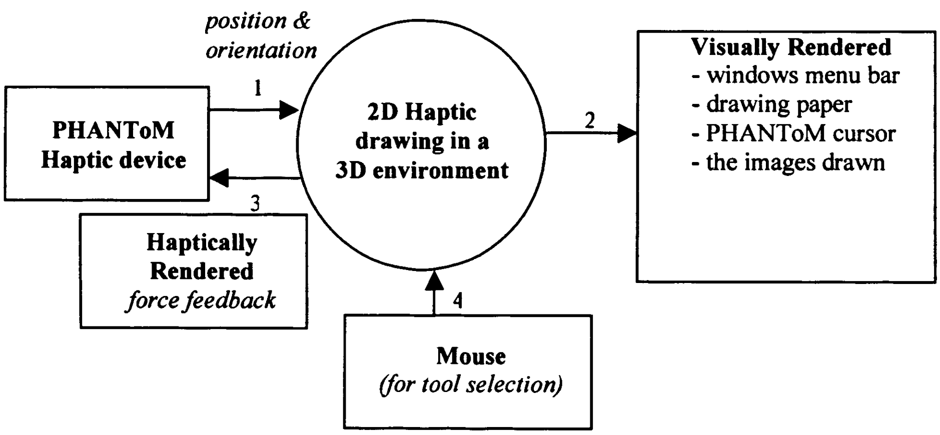


FIGURE 6-1: A SIMPLIFIED SYSTEM ARCHITECTURE OF HAPTICDRAW PROTOTYPE

Figure 6-1 follows a typical convention of a simple system architecture where there is an element of input, process and output. In a haptic drawing application, two outputs are expected which are the visual and haptic feedback. In Figure 6-1, the PHANToM haptic device is used to provide the 'input' to the system in terms of the position and orientation of the cursor point on the drawing interface. The arrow, labelled '1', represents this input. Upon touching the virtual drawing surface (process), lines will be drawn following from the movement of the PHANToM cursor. The arrow, labelled '2', represents this output. A specified (process) force feedback will be sent back to the PHANToM stylus in which a user can feel the haptic sensations of the drawing process. This explanation is in line with Burdea (2000) who noted that in response to changes in the virtual environment, the host computer sends position and feedback forces to the interface. This will result in forces felt by the users. In Figure 6-1, the arrow labelled '3' represents this output.

The HapticDraw prototype involved interactions in a 3D environment with the graphical part of the drawing performed in a 2D setting. The objects that will be graphically rendered throughout the drawing process include a set of toolbars for drawing selection, a drawing paper, a PHANToM cursor, which represents the pen-like tool in used and the lines drawn upon the movement of the PHANToM cursor. One main feature of this prototype is the ability to choose a pen-like tool and paper type from the toolbars using a mouse, labelled '4'. This input device initiates the changes of the haptic feedback in the system. Using the PHANToM, a user can draw or sketch on the interface and feel different haptic sensations as it interacts on the drawing surface.

6.2.2 Graphical Interface

As noted in Section 6.2.1, the visible output of the system process in Figure 6-1(HapticDraw prototype system architecture) is a set of rendered graphics, which appeared on the computer screen. In this section the graphics rendered are described further with regards to how they are being implemented and their associated functions. The graphical interface for the HapticDraw prototype consists of two main elements: (i) the window system, and (ii) all other graphics objects such as the drawing paper, the PHANToM cursor, and the lines (image) drawn on the screen as a result of the interaction.

The Window System

The window system makes use of the HapticView framework supplied by SensAble. As noted in Section 6.2.1, this API was chosen to generate a familiar feel and look of the main interface. The main purpose of this window system is to enable users to choose a pen-like tool and paper type for drawing. All the pen-like tools and the paper-type options noted in Section 3.4 are catered for. The haptic sensations provided in this prototype depend on the choice of these drawing tools. The design involves using the actual name of the pen-like tools used during the study with the artists as described in Chapter 3. Even though the pen-like tools and paper types do not have the real world graphical representations, the actual names associated to them are intended to provide some meaningful cues to users when they interact on the interface.

The Graphics Objects

There are three main graphics objects on the interface, namely, the drawing paper, the PHANToM cursor, and the lines (images) drawn.

Drawing paper

The implementation of the drawing surface in the prototype involves creating a (visual) drawing paper and a (haptic) paper base (see Figure 6-2).

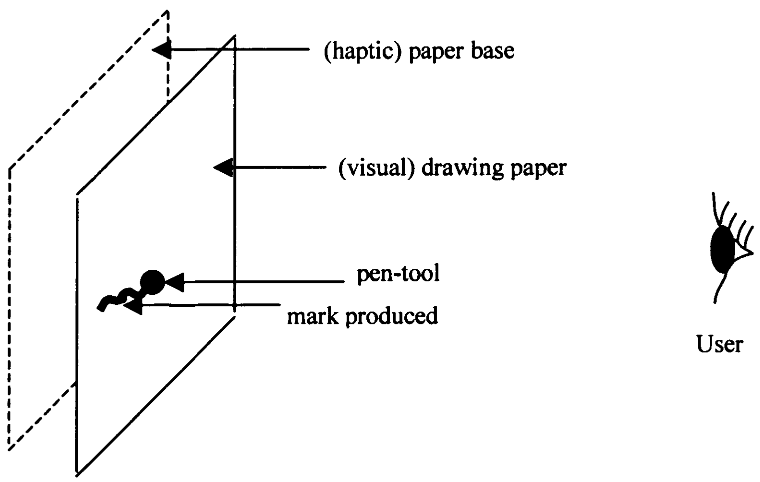


FIGURE 6-2 (VISUAL) DRAWING PAPER & (HAPTIC) PAPER BASE

The (visual) drawing paper is an area on the interface where the mark will appear during the drawing interactions. This area will be texture mapped with visual images of a drawing paper i.e. smooth or textured, depending on the choice made from the menu bar. The (haptic) paper base is designed to create a feeling that drawing is done on a hard surface. This will stop the users from going 'through' the paper. For this reason the (haptic) paper base is placed 'behind' the (visual) drawing paper i.e. out from the user's viewpoint and is not being graphically rendered. There is a gap created between the (visual) drawing paper and the (haptic) paper base to allow the implementation of the force feedback field in the design. This is discussed in the next section.

The (visual) drawing paper and (haptic) paper base are created using OpenGL and GHOST APIs, respectively. A square of size 120 units x 120 units is created to represent the (visual) drawing paper. The centre of the paper is positioned at coordinates (0, 0, -65). A cube of size 140 units x 140 units x 140 units is created and translated so that one of the cube faces is positioned parallel and behind the square (i.e. hidden from the user's view). This cube represents the (haptic) paper base. An example of the program code that performs the operations on the cube is as follows.

```
myPaperBase = new gstCube();
myPaperBase->setScale(70.0);
myPaperBase->setTranslate(0.0, 0.0, -8.0);
```

A simple illustration of the (visual) drawing paper and the (haptic) paper base from the top view (y-axis) is presented in Figure 6-3.

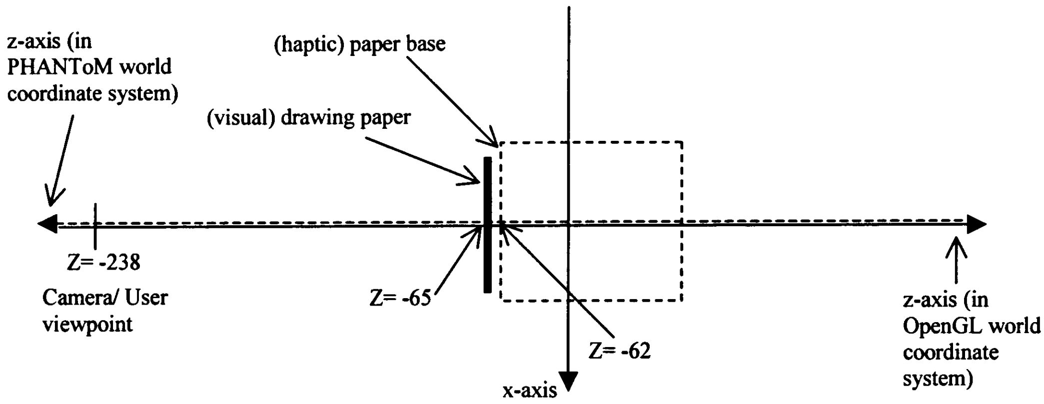


FIGURE 6-3 (VISUAL) DRAWING PAPER & (HAPTIC) PAPER BASE – TOP VIEW

PHANToM cursor

A triangle was created to function as the PHANToM cursor. The PHANToM position (x, y and z value) is attached to this triangle so that the coordinates for both PHANToM and triangle can correspond to one another. As this research is focusing on haptics rather than visualisation, the same triangle is used as a visual representation of the pen-like tool tip throughout the prototype. This triangle emulates as closely as possible the pen-like tool tip behaviour i.e. the tactile sensation felt (when drawing) of each pen-like tool chosen on the interface. The default pen-like tool for this prototype is a thin-tip pencil, which feels hard when used for drawing.

The lines (images) drawn

The lines or images drawn on the interface are a result of an interaction made during a drawing activity. These images appear when the PHANToM cursor touches the surface coordinates of the drawing paper. The thickness of these lines corresponds to the pen-like tool chosen. For example, a thin line is the visual result following from an interaction using a 3H pencil on smooth paper.

The fact that this thesis focuses on haptics makes the visualisation secondary to the research. Consequently, when implementing HapticDraw prototype, while the haptic feedback attempts to mimic as closely as possible the cues presented in Tables 3-5 and 3-6, only a simplification of line thickness is made with respect to the pen-like tools used. For the implementation purpose in this research, a pencil with a thin tip will make a small, light line while a wide tip will produce a slightly bigger and darker mark. Regardless of the tip size, a pen will produce a bigger mark than a thin tip pencil. Both crayon and charcoal will make the biggest line as compared to a pencil and a pen. In the actual implementation three different sizes of line are used. '3H pencil', '2B pencil', and 'ball-point pen' have the same thin line;

'graphite pencil', 'felt-tip pen', and 'roller-ball pen' have a medium size line; 'crayon', and 'charcoal' have the same large line. These sizes apply to both on the 'smooth' and 'rough paper'.

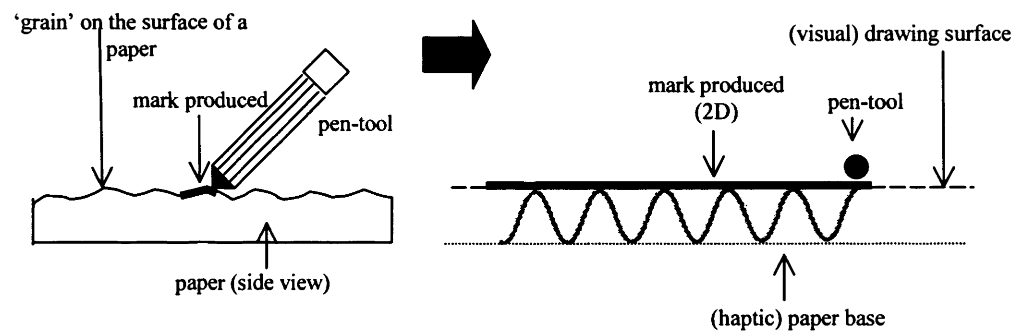
6.2.3 The Haptic Effect

This section focuses on the haptic output of the system process in Figure 6-1. It discusses the rationale of the haptic implementation and how the dimension cues highlighted in Chapter 3 are integrated in the prototype.

The Rationale

The HapticDraw prototype provides users with a tactile experience during their drawing interaction on the interface. It involves 2D drawing in a 3D environment. The prototype follows the analogy of drawing in the real world (see Figure 6-4(a)) in that users can draw on the surface paper and feel the tactile sensation of the interaction. Figure 6-4(b) shows an example of a line drawn on the drawing surface and the surface texture profile assigned to the haptic paper base.

REAL WORLD ENVIRONMENT	HAPTICDRAW PROTOTYPE



(a) Drawing on a surface of paper in the real world environment (side view)

(b) An adaptation of concept (a) in HapticDraw prototype (not to scale)

FIGURE 6-4: AN ANALOGY OF A DRAWING INTERACTION

In Figure 6-4(b) the surface texture profile is represented by a series of sine waves that is implemented in the gap between the visual drawing surface and the haptic paper base. The sine waves could easily allow changes on the surface texture to be made in order to simulate various haptic sensations. In this prototype, the implementation of haptic sensation is inspired from the idea that interface designers use findings on how people perceive and manipulate active and passive exploration of touch (Klatzky and Lederman, 2002) to simulate haptic behaviour for interactions. By manipulating the surface texture profile of the drawing surface, an illusion of interacting on various media with drawing implements could be created. In other words, by changing the surface texture profile upon selecting a pen-like tool and paper type combination we are able to simulate various tactile sensations when, say, interacting using a pencil on smooth paper and using crayon on rough paper. Burdea (2000), as noted in Chapter 2, supports this idea. He highlights that surface texture can be used for physical modelling on the smoothness and roughness of a virtual object. McGee et al (2001) proved that texture roughness could be discriminated by changing the surface texture profiles: haptic perception is a result of an active exploration whereby users understand and interpret the experience they have just felt.

Implementing the Haptic Effect

In general, the simulation of haptic feedback in this prototype depends on the parameter settings provided by GHOST SDK. Consequently, the prototype follows the contact force model as used in GHOST SDK. A user can feel this feedback as they explore the PHANToM cursor on the surface texture of the (haptic) paper base. From Chapter 3, three haptic dimension cues, i.e. bumpiness, scratchiness and stickiness and a neutral point, smoothness, have been considered to be important for the integration.

The integration of the three haptic dimension cues and their neutral point in HapticDraw prototype involved an adaptation of Wall and Harwin's (2000) 2D sinusoidal wave model implemented on the paper surface was used. In this prototype the sinusoid is implemented on the X and Y-axes of the haptic paper base. The variation of haptic sensation implemented for the drawing surface is done by manipulating the frequencies and amplitudes of the sine waves, and manipulating the parameters supported by PHANToM, which are the coefficients of static and dynamic friction, and values for stiffness and damping factors. According to Castle et al (2002), the stiffness and damping parameters act as internal friction of an object.

In integrating the haptic effects, all parameters are treated inter-dependently. It should be emphasised that the exercise described in this section only provides a simple guideline for such implementation. The basic concept to implement the haptic effects is as follows:

<u>Bumpiness</u> (*rough; rough/ bumpy*)

By manipulating the amplitude and frequency of the waves a bumpy feeling could be felt. This could be achieved for example by having a high amplitude and low frequency of the waves. This approach is justified by McGee's (2001) research work on surface texture roughness.

Stickiness (*sticky, creamy, velvety*)

The stickiness sensation is implemented by manipulating the friction parameter settings. This idea is replicated from approaches used by Foskey et al (2002), Castle et al, (2002), Iinuma et al, (1999) and Yu et al (2001) who manipulated the friction values to get a stickiness effect. Keeping the coefficients of static and dynamic friction high creates a 'sticky' feeling of the interaction.

Scratchiness (*hard, dry, stiff, sharp/scratchy*)

Manipulating the frequency of the sine waves implemented on the haptic paper base simulates the scratchiness effect. This is related to the bumpiness effect as well. Keeping the amplitude low, making the frequency high, and varying the frequencies of the X and Y-axes of the haptic paper base creates a scratchy sensation for the drawing interaction. In this prototype, the scratchiness effect has been implemented through trial and error. This effect was tested in a formative evaluation performed throughout the development process.

Smoothness (*smooth, silk, flow, glide*)

The smooth sensation is implemented by manipulating the friction parameter settings. Foskey et al (2002) stated that the lack of overly friction rendering can create an overly smooth feeling during a haptic interaction. Yu et al (2001) used this approach when implementing a slippery sensation on a simple haptic graph. By keeping the coefficients of static and dynamic friction low could create a smooth sensation. This is in contrast with implementing the stickiness effect.

It should be noted that the initial implementation of the HapticDraw prototype is taking the form of an object-based metaphor interface design in which the pen tools and paper types combinations are involved. In such a case, the three dimension cues need to be manipulated for each of the combinations. The datasets involved in the object-based metaphor interface design could be used as a basis to implement the haptic effect for a textual description metaphor interface design option. An example of program codes to illustrate the implementation of the bumpiness, stickiness, scratchiness, and smoothness effects in a textual description metaphor interface design, is shown in Appendix 6-1.

6.3 The Implementation of the Interface Design

This section describes the implementation of the interface design for the HapticDraw prototype. The implementation process provides detailed information as to the appropriateness of integrating haptic cues that the chosen haptic device is capable of producing. Several informal tests that have been carried out to calibrate the tactile sensations of the pen-like tool and paper type combinations of the HapticDraw prototype are described. These tests were small scales and were performed as part of a formative evaluation during the development stages. It should be noted that the evaluator involved in this evaluation might not necessarily be an artist. The feedback received in each test was used to re-design the initial prototype.

6.3.1 The Early Version

The early stage of the implementation involved development of a real world object-based metaphor interface. The main focus at this stage was to create the graphic and design layout of the interface. Figure 6-5 presents a sample screen shot of the earlier version of the prototype.

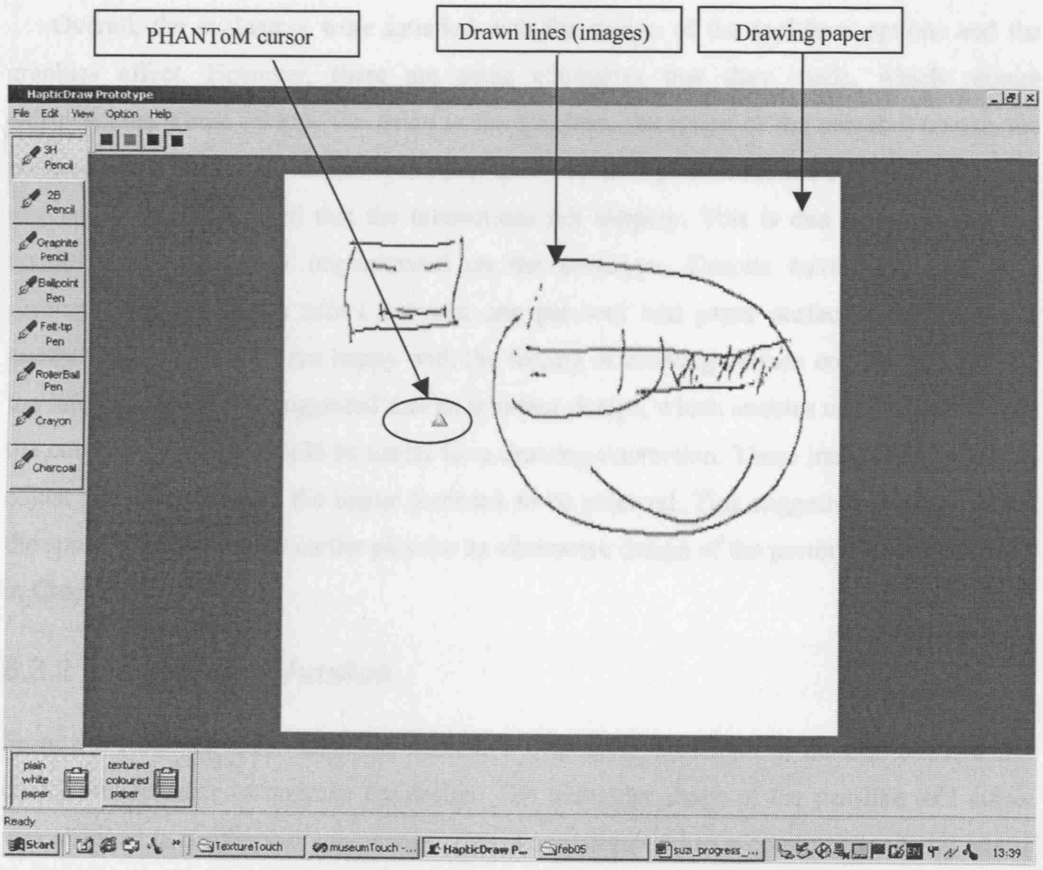


FIGURE 6-5: GRAPHICS OBJECTS OF THE HAPTICDRAW PROTOTYPE

Figure 6-5 highlights the window system and the graphics objects on the interface. In the early stage of the development a fixed coefficient value for stiffness and damping were applied on the haptic paper base. These features create a feeling of interacting on a hard drawing surface, as one could feel the hardness of the haptic paper base.

Formative Evaluation - Test 1

The main aim of the first test was to validate the appropriateness of the graphic and design layout of the interface. It was also used as an initial step towards testing the haptic effect of the prototype. Eleven evaluators took part in this informal testing. They were among the researchers from the Computer Science and Psychology Departments at University College London. The test was conducted at a Computer Science laboratory where the PHANToM was kept. Participation in this test was totally voluntary.

In the test the evaluators were asked to make a free drawing or sketching using the prototype. They had to comment out loud on the interface layout, the marks appearing on the screen and the tactile sensation of the drawing interaction. The test was audio recorded for future reference on the remarks made by the evaluators. Also, the researcher noted down the comments made for further actions.

Overall, the evaluators were satisfied with the design of the tool bars options and the graphics effect. However, there are some comments that they made, which require enhancement. These include the delay in the graphics, the shape of the pen-tool cursor, the position of the paper type selection and the "clear screen" option. In terms of the haptic effect, evaluators generally noted that the interactions felt slippery. This is due to the frictionless condition effect initially implemented on the prototype. Despite having difficulties in distinguishing the haptic effect between one pen-tool and paper surface combination to another, the evaluators were happy with the feeling of drawing surface contact provided on the interface. They also suggested that an interface design, which enables users to manipulate the condition settings, would be useful for a drawing interaction. These include the ability to adjust the pen width and the haptic feedback to be received. This suggestion has confirmed the appropriateness of our earlier plan for an alternative design of the prototype as highlighted in Chapter 5.

6.3.2 The Second Version

From the feedback received in the formative evaluation described in Section 6.3.1, a few changes were made to improve the design. The triangular shape of the pen-like tool cursor was changed to a spherical appearance. This is to correspond to a comment made by one of the evaluators who said that a triangular shape could confuse a user in determining the point that should start marking the line. A spherical shape was suggested as it may allow the user to assume that the drawing mark will start at the centre of the cursor. The position of the paper types selection was moved closer to the pen-like tools menu bar. This is to address a comment made by an evaluator who noted that the menu bars presented on the interface were 'scattered'. The clear screen option was initially embedded in the pull-down menu selections (see Figure 6-5). This has created some difficulties in learning to use the interface as the users assumed that they are not able to clear the drawing. To rectify this problem a clear button was created and positioned closer to the pen-like tools and paper types menu bars. This has eliminated most of the pull-down menu options on the interface. However, the comments made on the delay in rendering the graphics have not been addressed because it is beyond the scope of this research project.

In order to enhance the haptic effect, an appropriate amount of force feedback has been adjusted in accordance to the pen-like tool and paper type combinations. The effect was implemented by changing the haptic paper base surface texture profiles with respect to the pen-tool and paper type combinations. Each profile comprises a different set of coefficient values for the stiffness, damping, and static and dynamic friction features. It has also a different set of amplitude and frequency values for the surface texture. A full set of the datasets used for this testing is presented in Appendix 6-2.

Formative Evaluation - Test 2

The main aim of the second formative evaluation test was to validate the appropriateness of the haptic effects when interacting using various pen-like tools on paper types. Six evaluators took part in this informal testing. They were among the members of staff from the Computer Science and Psychology Departments at University College London, and postgraduate students from other universities in London.

The evaluators were asked to draw or sketch on the interface using all sixteen combinations of pen-like tools and paper types. For each combination, the evaluators have to say out loud what tactile sensations were felt during the interaction. The test was audio recorded for future reference and the researcher noted down comments made by the evaluators for further actions.

For this formative evaluation test, the labelling of the pen-like tools such as '3H pencil', 'crayon' and 'charcoal' and paper types i.e. 'smooth' and 'rough' was intended to follow the real world naming convention. The intention is to assist the evaluators to relate these names and build some expectations on how the tactile sensation would feel like in the real world. Their previous experience may be useful in validating the appropriateness of the tactile cues integrated in the prototype. At the same time the evaluators were also given the real implements used in the earlier study with the traditional artists in order to have a better perception of the haptic feedback when comparing the interactions in the real and computer environments. Using the same naming convention as in the real world may invoke some bias in the evaluators' judgement when determining the tactile sensation during the interactions. However, it is important at this stage to use such names because the difference in force feedback has been reported as difficult to differentiate.

In this informal test, the evaluators noted that the haptic experience when interacting using the real implements might not be the same with the computer environment. However, they mentioned that in the prototype tested, the difference in terms of the tactile sensation between one pen-like tool and paper type combination to another could be felt and are of the appropriate scale. For example, the pencils are expected to be harder and rougher than when using pens. In this test, with an exception of the scratchiness effect, bumpiness, stickiness and smoothness have been successfully implemented.

6.3.3 The Third Version

Following from the formative evaluation study findings obtained in Section 6.3.2, the prototype has been improved in terms of adjusting the haptic effect so that the scratchiness effect could be felt. The main changes include decreasing the amplitudes and increasing the frequencies of the surface texture profiles. In such cases the amplitudes and frequencies for X and Y-axis were differed too. This is mainly through trial and error. The revised dataset is presented in Appendix 6-3.

Formative Evaluation - Test 3

The main aim of the third formative evaluation test was to validate the appropriateness of the three haptic dimension cues i.e. bumpiness, stickiness and scratchiness, and the neutral point i.e. smoothness effects implemented for the pen-tool and paper combinations. The improved version of haptic interface resulted from the previous formative evaluation (Test 2) was used. Six evaluators took part in this informal testing. These evaluators were among the researchers in the Computer Science and Psychology Departments at University College London.

The test was divided into two parts. In this section, the presentation flow for each of these parts will follow the order of: the interface involved, the tasks given, the data analysis performed and the findings obtained.

<u>Part 1 – Identifying 5 Surface Textures</u>

The first part involves validating five examples of surface textures by identifying the tactile sensations felt and rating the quality of haptic features (refer Table 6-1). These examples are chosen to represent some 'extreme cases' in terms of the haptic effect such as being the most bumpy, most scratchy, most sticky and smoothest pen-tool and paper type combination datasets. The intention is to assist evaluators in distinguishing the tactile sensations easily. This exercise also serves as a training activity before performing the second part of the test. A sample of the interface design used in this test is presented in Appendix 6-4.

The evaluators were asked to make a haptic exploration on the interface and name the tactile sensation when interacting on each texture. Unlike in formative evaluations Test 1 and 2, no visual cues in terms of line marks were provided upon the interaction in Test 3. After each exploration, the evaluators were asked to rate the bumpiness, stickiness and scratchiness effect felt on a five-point rating scale. This rating scale was designed based on the findings obtained from the Card Sorting activity described in Section 3.4.1. A sample set of a rating scale questionnaire is presented in Appendix 6-5. A simple analysis was conducted in which the scores rated by the evaluators were plotted on a graph (see Appendix 6-6). The pattern emerged from this exercise was observed. A summary of the results is presented in Table 6-1.

TABLE 6-1: FINDINGS FROM IDENTIFICATION OF THE 5 SURFACE TEXTURES

Texture	Pen-tool type	Paper type	Sensation	Evaluators' opinions/ Other Remarks
1	Crayon	Smooth	Sticky Bumpy	▪ Sticky (i.e. 4 evaluators rated 3 and above) ▪ Low scratchy (i.e. 3 evaluators rated 2 and below) ▪ No real pattern for bumpy
2	Graphite pencil	Smooth	Smooth	▪ Low bumpy, scratchy and sticky, which indicates that the interaction is smooth and flowing
3	Ball-point pen	Smooth	Scratchy	▪ Low bumpy and low sticky ▪ Scratchy (i.e. 3 evaluators rated either 4 or 5)
4	2B pencil	Rough	Smooth Bumpy	▪ Low scratchy (i.e. 5 evaluators rated 3 and below) ▪ Low sticky (i.e. 3 evaluators rated two and below) ▪ Bumpy (i.e. 5 evaluators rated 3 and above)
5	Charcoal	Smooth	Scratchy Bumpy	▪ Scratchy (i.e. 6 evaluators rated either 3 or 4) ▪ Bumpy (i.e. 5 evaluators rated 3 and below) ▪ Low sticky which means flowing

From Table 6-1, the columns representing the evaluators' opinions and the intended sensation for the haptic textures tested were compared. This comparison is in fact meant to assess the evaluators' opinions with the intended haptic feedback of the associated pen-like tool and paper type combinations as to whether the sensations met the haptic design requirement. A summary of the intended tactile sensations for pen-like tool and paper type combinations for the prototype is presented in Appendix 6-7. The findings from the first part of the test showed that the evaluators were able to distinguish the tactile sensations of the five surface textures and their judgement on the rating scales nearly correspond to the design requirements.

Part 2 – Identifying the Surface Textures

The second part involves validating all sixteen combinations of pen-like tool and paper type. In this test the labelling of the pen-like tools used in the formative evaluation (Test 2) was changed to "texture" e.g. "texture 1" and "texture 2". Likewise, the paper type was called "Set A" and "Set B" to correspond to smooth and rough paper, respectively. The intention was to avoid evaluators having preconceptions of interacting using a particular pen-like tool on a paper type. A sample of the interface design used in this test is presented in Appendix 6-8.

All six evaluators performed the same procedures in rating the bumpiness, stickiness and scratchiness effects of the sixteen combinations of surface textures corresponding to the different pen-tool and paper type combination datasets. However, in this part the evaluators have to decide which of the 30 selected vocabularies of tactile cues obtained from the study with traditional artists e.g. "bumpy", "chalky", "coarse" and "creamy" can best represent the tactile sensation felt during the interaction. These vocabularies were used earlier in the Card Sorting activity described in Section 3.4.1. This exercise was carried out to crosscheck the vocabularies that the evaluators said with the original design requirements for individual pen-like tool and paper type combination (see Appendix 6-9 for an example of tactile information for a pen-like tool and paper type described in Chapter 3).

Like the study results in Part 1, the evaluators managed to highlight the tactile sensation felt based on the interactions. A similar technique to analyse the data as in the first part is used. (See Appendix 6-10 for the plotted graph). A summary of the results for haptic textures and Set A combinations is presented in Table 6-2.

TABLE 6-2 FINDINGS FOR SET A (PAPER TYPE: SMOOTH)

Texture	Pen-tool type	Sensation	Evaluators' Opinions/ Other Remarks
1	2B pencil	Smooth	▪ Low bumpy which indicates smooth and flowing ▪ Low scratchy ▪ Medium sticky (i.e. 5 evaluators rated either 3 or 4)
2	Charcoal	Scratchy Bumpy	▪ Low bumpy (i.e. 5 evaluators rated either 1 or 2) ▪ Scratchy (i.e. 4 evaluators rated 4) ▪ Low sticky (i.e. 6 evaluators rated 3 and below)
3	Ball-point pen	Scratchy	▪ Low bumpy ▪ Scratchy (i.e. 5 evaluators rated either 3 or 4) ▪ Low sticky (i.e. 6 evaluators rated 3 and below)
4	Graphite pencil	Smooth	▪ Low bumpy, scratchy and sticky which indicates the interaction is smooth and flowing
5	Crayon	Sticky Bumpy	▪ Sticky (i.e. 5 evaluators rated 3 and above) ▪ Low scratchy (i.e. 5 evaluators rated 2 and below) ▪ No real pattern for bumpy
6	3H pencil	Scratchy	▪ Scratchy (i.e. 6 evaluators rated either 3 or 4) ▪ Low bumpy and low sticky (i.e. score 3 and below)
7	Roller-ball pen	Smooth	▪ Low bumpy (i.e. 5 evaluators rated 3 and below) ▪ Low scratchy (i.e. 5 evaluators rated 3 and below) ▪ More towards medium sticky which indicates dragging (i.e. 5 evaluators rated either 3 or 4)
8	Felt-tip pen	Sticky	▪ Low bumpy (i.e. 5 evaluators rated either 1 or 2) ▪ No real pattern on scratchy and sticky but scores are more towards the low end (i.e. below 3)

Table 6-2 shows the study findings for tactile sensations in pen-like tools and smooth paper selections, which were represented using combinations of haptic textures and Set A. The evaluators' opinions on the tactile sensation perceived of the haptic textures were compared with the intended haptic sensation. The study findings revealed that the evaluators' judgement on the haptic feedback perceived nearly match the intended sensation. Such results indicate that scratchiness, bumpiness, and stickiness effects have been appropriately implemented for the pen-like tools and smooth paper combinations.

A similar kind of data treatment and analysis as when using Set A was replicated for Set B. A summary of the results is presented in Table 6-3.

TABLE 6-3: FINDINGS FOR SET B (PAPER TYPE: ROUGH)

Texture	Pen-tool Type	Sensation	Evaluators' Opinions/ Other Remarks
1	2B pencil	Smooth Bumpy	▪ Medium bumpy ▪ Low scratchy and low sticky which indicates that the interaction is flowing (i.e. scores are more towards the low end i.e. 3 and below)
2	Charcoal	Scratchy Bumpy	▪ Low bumpy (i.e. 5 evaluators rated 1 or 3) ▪ Scratchy (i.e. scores more towards the low end of the rating scale i.e. 3 and below) ▪ Low sticky (i.e. 5 evaluators rated 3 and below)
3	Ball-point pen	Scratchy	▪ Low bumpy (i.e. 4 evaluators rated either 1 or 2) ▪ No real pattern for scratchy (distributed) ▪ Low sticky (i.e. 6 evaluators rated 3 and below)
4	Graphite pencil	Smooth Bumpy	▪ Low bumpy, scratchy and sticky (i.e. all scores are towards the low end of the rating scale i.e. 3 and below)
5	Crayon	Smooth Bumpy Sticky	▪ No real pattern for bumpy, scratchy and sticky (i.e. all distributed but more towards the low end of the rating scale)
6	3H pencil	Scratchy	▪ Low bumpy and low sticky ▪ Scratchy (i.e. all evaluators rated from 2 to 5 and more towards the high end of the rating scale i.e. 3 and above)
7	Roller-ball pen	Smooth Scratchy	▪ No real pattern for bumpy, scratchy and sticky (i.e. all distributed)
8	Felt-tip pen	Scratchy	▪ Low bumpy (i.e. 5 evaluators rated either 1 or 2) ▪ Low Sticky (i.e. 5 evaluators rated either scale 1 or 3) ▪ Scratchy (i.e. all evaluators rated from 2 to 5)

Table 6-3 shows the study findings for tactile sensations in pen-like tools and rough paper combinations represented using combination of haptic textures and Set B. When the last two columns from the table were compared, the results revealed that evaluators' opinions were not much different from the intended tactile sensation. Similar to the deduction made for results in Table 6-2, these findings imply that the three haptic dimension cues have been integrated appropriately for the combinations on a rough paper.

6.4 HapticDraw Prototype - Three Versions of the Interfaces

Following from the formative evaluation presented in Section 6.3, a revised version of a set of HapticDraw interface designs was finalised so that the prototype was ready for further evaluation. In this section three versions of the final interface are presented.

6.4.1 The Real World Object-Based Metaphor Interface Versions

This interface design consists of a selection of pen-like tools and paper types in which the actual names as used in the real world are provided. This version of the interface has the parameter settings that manipulate the static and dynamic coefficients of friction, stiffness and damping values, amplitudes and frequencies for both X and Y values of the sine waves of the surface texture profiles for each pen-like tool and paper type combination. A variable haptic version of the interface is established in the sense that a different haptic sensation of the drawing interactions could be received by choosing the pen-like tool and paper type combinations they wish to use. The metaphor used in the interface is meant to provide some cues of how the tactile sensation will feel. A summary of the dataset values used in this version of interface is presented in Appendix 6-11. This revised metaphor interface design for HapticDraw prototype is presented in Figure 6-6.

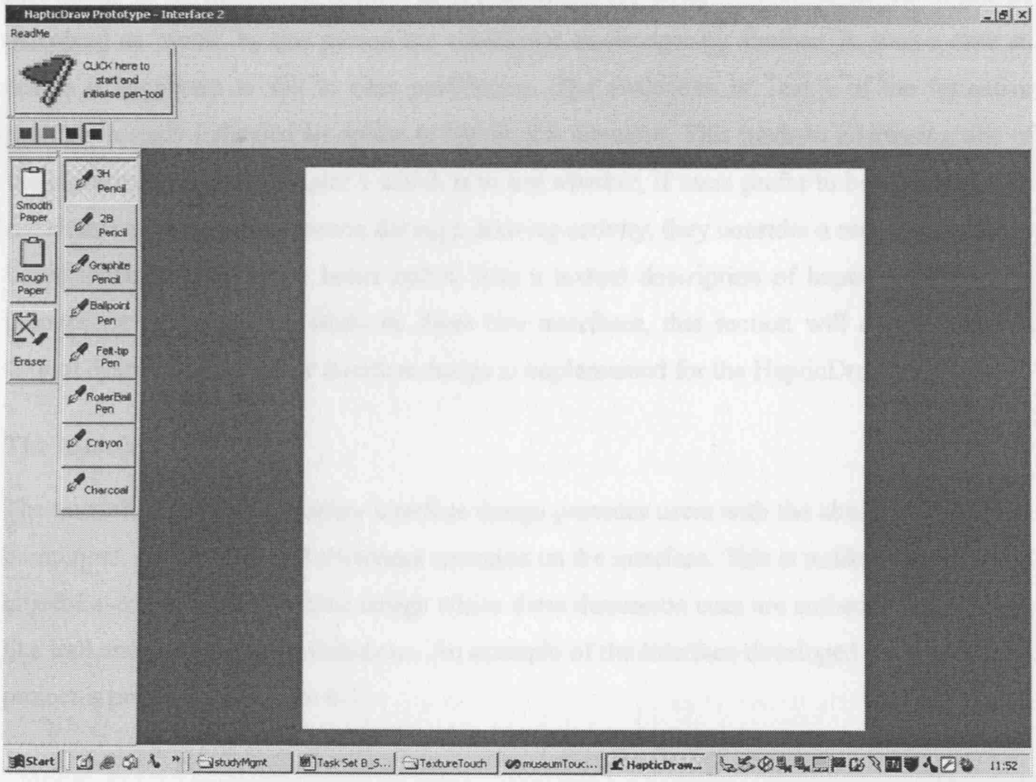


FIGURE 6-6 REVISED VERSION OF REAL WORLD OBJECT-BASED METAPHOR INTERFACE

In Section 1.2, it is stated that the main objective of this thesis is to investigate whether a variable haptic interface design is more preferred than its fixed counterpart. In working towards achieving this objective, an interface like that shown in Figure 6-6 was prepared but only provided with a fixed tactile sensation regardless of the pen-like tool and paper type chosen. This leads to a version of the interface that has a real world object-based interface metaphor whose underlying haptic feedback is fixed. This implementation is to allow a comparison to be made between the two interfaces i.e. fixed vs. variable haptic interfaces. For this purpose, the parameter settings for the fixed interface are set to zeros with the exception of the stiffness and damping coefficients that are assigned to 0.50 and 0.002 throughout.

These parameters are given some values to create an illusion of drawing on a hard surface. This is as noted in the description of an earlier version of the object-based metaphor interface design described in Section 6.3.1. This concept has been used in Test 1 of the formative evaluation study.

6.4.2 The Textual Description Metaphor Interface Version

It should be re-emphasised that haptic sensation is very context dependent in the sense that it depends on the application in question and also on users preferences. In general, haptic force perception is an individual matter: as Yu et al (2003) note, a force feedback might be perceived as 'weak' by one person but considered as stronger by another. In such a case an option is suggested to suit to ones preferences. The evaluators in Test 1 of the formative evaluation study indicated an option to handle this situation. This leads to addressing one of the objectives stated in Chapter 1 which is to test whether, if users prefer to be able to decide the choice of the tactile sensation during a drawing activity, they consider a real world object-based metaphor interface a better option than a textual description of haptic feedback. To prepare for a comparative study on these two interfaces, this section will describe how a textual description metaphor interface design is implemented for the HapticDraw prototype.

The Interface

The textual description metaphor interface design provides users with the ability to adjust the bumpiness, scratchiness and stickiness sensation on the interface. This is unlike the real world object-based metaphor interface design where these dimension cues are embedded in the pen-like tool and paper type combinations. An example of the interface developed in this research project is presented in Figure 6-7.

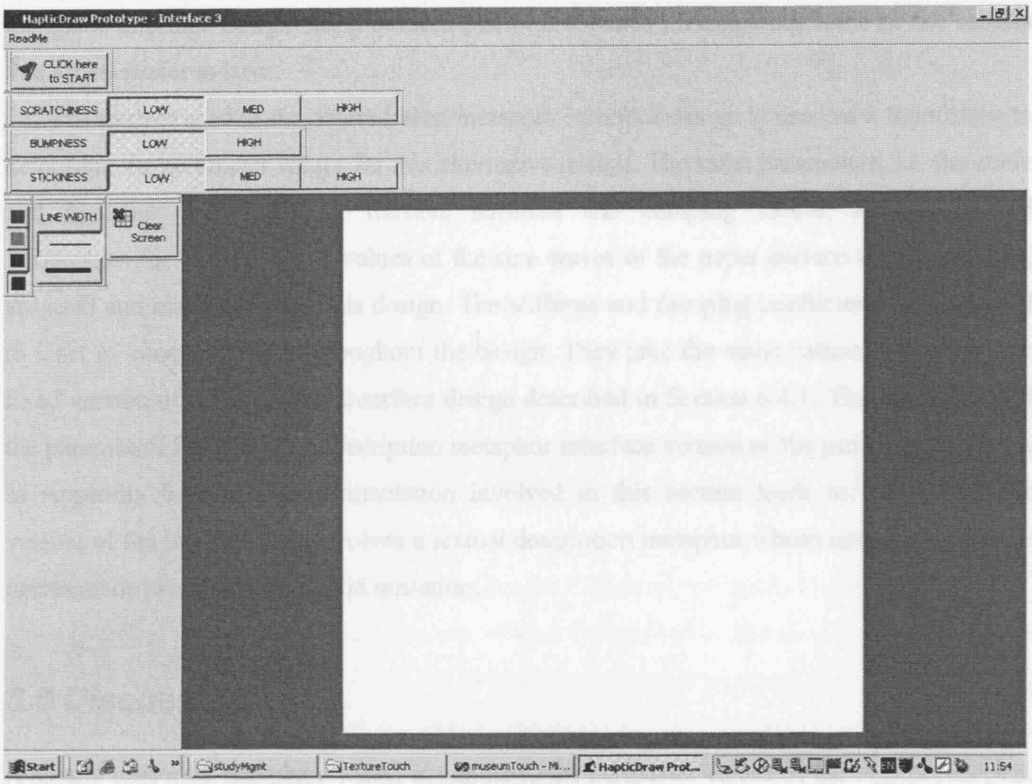


FIGURE 6-7 TEXTUAL DESCRIPTION METAPHOR INTERFACE

In Figure 6-7, users are given three different choices i.e. ‘low’, ‘medium’ and ‘high’ options for the scratchiness and stickiness effects, and ‘low’ and ‘high’ for bumpiness. This design is intended to be as simple as possible in order to reduce the amount of development time whilst maintaining the validity of the concepts in question. In this design, by using a mouse click users are able to choose the combination of haptic cues before drawing on the interface. For this investigation, the ‘low’ options for all haptic dimension cues are set as the default value. Like the haptic cues, the visual line width can also be determined and is assigned as ‘thin’ for the default setting in this prototype.

The Underlying Parameters of Dimension Cues

The idea of having a textual description metaphor interface design in the implementation prompts a question pertaining to the tactile sensation that we should feel from the three combinations of dimension cues. This addresses the matter raised in Chapter 1 which is when interacting in a computer environment do users still want to have a tactile sensation that feels similar to that in the real world or something that feels different but acceptable and creative. Scali et al (2002) highlight that the percentage of computer usage among artists in supporting their creative work is very low. They report that artists are not tied to the need to digitise their designs and would only use computers where they offer advantages over traditional tools and have features relevant to their activities. The parameter values set in this textual description metaphor interface design can provide a platform towards investigating some of the criteria that artists prefer to have.

The dataset used in the object-based metaphor interface design is used as a foundation to determine the parameter values for this alternative design. The same parameters, i.e. the static and dynamic coefficients of friction, stiffness and damping values, amplitudes and frequencies for both X and Y values of the sine waves of the paper surface texture profiles, are used and manipulated in this design. The stiffness and damping coefficients are assigned to a set of constant values throughout the design. They take the same values as those in the fixed version of the metaphor interface design described in Section 6.4.1. The full dataset of the parameters for the textual decription metaphor interface version of the prototype is shown in Appendix 6-12. The implementation involved in this section leads to having another version of the interface that involves a textual description metaphor whose underlying feature corresponds to an intuitive haptic sensation.

6.5 Discussion

A simple rendering technique which manipulates the parameter values of the PHANToM, i.e. the coefficients of static and dynamic frictions, and the stiffness and damping factors described in Chapter 4 have been used to demonstrate how the conceptual designs could be put into practice. In general, the haptic effects are implemented by manipulating the surface texture of the drawing paper. Changing the surface texture profile for each combination of pen tools on paper type is a simple way of integrating such cues in a drawing application. This idea is adapted from McGee et al (2001) in rendering different texture surfaces to perceive texture roughness. This rendering technique is chosen on the basis that this research project focuses on the perceptual aspect of haptic interactions; hence, a simple rendering technique is adequate to achieve the goals.

The techique is enhanced by adding a 2D sinusoidal wave on the haptic surface paper and manipulating the parameter values of the PHANToM, i.e. the coefficients of static and dynamic frictions, and the stiffness and damping factors. By adjusting the frequencies and amplitudes of the 2D waves and manipulating the haptic parameters from PHANToM, we are able to mimic the haptic sensations of pen tools on drawing papers. This technique has been used to implement the bumpiness, stickiness, scratchiness, and smoothness effects.

McGee's et al (2001) approach in perceiving texture roughness has not been considered for integration of haptic cues specifically in a drawing domain. As discussed in Chapter 4, McGee et al highlight the difficulties in discriminating texture perception and suggests a multimodal approach to handling this problem. Specifying the context under study and providing metaphor to cue users so that they are able to relate to their tactile experience in the real world could tackle this situation. This technique has also enabled us to implement synthetic textures quite similar to those in the real world. The scope of this implementation work itself is considered unique because this integration of haptic cues in a drawing domain is the first of its kind.

The alternative to the object-based metaphor interface design was implemented. The textual description metaphor interface is an option for designers to represent the haptic dimension cues in the application. This is the design that needs to be compared with the object-based metaphor interface in order to find out which representation of the haptic interface users prefer to interact with and why. It is also a step towards investigating whether users prefer to have tactile sensations that mimic real world interaction or alternatives. These two interfaces implemented represent the variable haptic interfaces as stated in Section 1.2. Both interfaces have a variation of haptic sensation that reflects the metaphor used.

The choice of haptic rendering techniques used may pose a limitation to the prototype. This rendering technique depends on users' lateral exploration on the surface of the paper. It does not follow the real world behaviour such as the amount of pressure applied on the paper surface. The simple sinusoidal wave model used in the implementation may miss out details of haptic perception during an exploration. Ideally, an advanced rendering technique should be able to mimic a better sensation more like those in the real world. There are several successful implementations for texture rendering methods, using various texture geometrical models that have been reported, an investigation to seek for the best technique is beyond the scope of this thesis.

At this stage, the practical work in terms of implementing the two haptic design options based on the concept of metaphor discussed in Chapter 5 has addressed research question 3, i.e: *How do we integrate the haptic features identified in a design interface?*
Both Chapters 5 and 6 have dealt with this question by providing a conceptual design and putting it into practice. The reification of metaphor as emphasised by Blackwell (2006) motivates the development of the conceptual ideas. However, the usage of metaphor in representing the haptic information needs to be tested in terms of its affect on user experience when using the interface. In this case, another interface which takes the form of the real world object-based metaphor was implemented but with a fixed haptic sensation. This interface represents the fixed haptic interface stated in Section 1.2.

Yu and Brewster (2003) caution on the user haptic perception when distinguishing force feedback (Section 1.1). The kind of haptic sensation an application should have varies depending on its purpose in the system. However, with regard to an art-related application where creativity is an essential criterion in its process of interaction, the question is: is mimicking the real world interactions, in terms of the touch sensation, really what users prefer to have? Would a creative haptic sensation be an alternative for the underlying feature of such a system? These are some of the haptic features that we should test with a group of target users of a haptic drawing system. An investigation on user haptic experience when interacting with the three interfaces presented in this chapter may answer these questions.

6.6 Chapter Summary

This chapter has integrated the set of dimension cues (i.e. bumpiness, scratchiness and stickiness) highlighted in Chapter 5 into a drawing prototype, called HapticDraw. The objective of this integration is to prepare for two versions of haptic interfaces, i.e. fixed and variable haptic sensation, in order to address the research questions stated in Chapter 1. Within the variable haptic sensation interface, two different design representations are provided i.e. the object-based metaphor and textual description metaphor interfaces. The intention is again to prepare for further testing in order to address the research questions in this thesis.

The implementation of the HapticDraw prototype involves designing a window system for tools selection, supporting some relevant graphical interfaces and simulating the haptic effect. The prototype is mainly based on two possible events that need to occur simultaneously during an interaction which are: a 2D mark appearing on the visual drawing paper and the haptic feedback associated to the interaction when the pen-like tool touches the surface of the paper. The PHANToM cursor represents the tip of the pen-like tool whereas the drawing paper involves the drawing surface, which is for the graphics and a haptic paper base where the users could feel the hardness of the paper.

The haptic rendering technique chosen in this implementation is influenced by the concept of active exploration and the success of texture rendering in enabling users to perceive the tactile sensation of an interaction. A simple rendering technique that includes changing the surface texture profiles of the paper surface is involved. Haptic sensation can be felt upon exploration of the pen-like tool cursor on the haptic paper base that has a different haptic surface texture profile and properties depending on the pen-tool and paper type combinations. The variation of tactile sensation upon such combinations is intended for the users to choose the expected sensation based on the metaphor provided. In other words, this design is a variable haptic interface in the sense that users are able to receive different types of haptic sensation with respect to the interface metaphor. Using the same design representation, a fixed haptic sensation interface has been prepared in which no changes in terms of tactile sensation can be felt with respect to the pen-like tools on paper type combinations.

The prototype has undergone a few formative evaluations and redesign cycles. The tests include checking the appropriateness of the graphics and calibrating the haptic sensation of pen-like tools and paper type combination. Improvements to the design have been carried out based on the feedback received.

The tactile sensation of the revised version of the object-based metaphor interface design has been used to guide the implementation of the textual description metaphor interface design. It uses some of the parameter settings of the object-based metaphor interface in implementing the haptic effect of the three dimension cues. Unlike the tactile feedback in the object-based metaphor interface design, the sensation in the textual description metaphor interface design is intended to be intuitive and not replicating the real world tactile experience.

This chapter demonstrates how a set of haptic dimension cues obtained from user experience of drawing in the real world can be integrated in a computer environment. It should be noted that this is the first system (in the drawing domain) to integrate haptic cues obtained from user experience in a traditional drawing into a computer environment. The limitation of the haptic rendering technique used may cause some sensations to be missing during a drawing interaction. However, it is important to test the user haptic experience when interacting with this prototype.

Chapter 7 Evaluation Study

7.1 Introduction

This chapter presents an evaluation study of the haptic drawing interfaces developed and described in Chapter 6. It forms the third and final part of the practical work that aims to address the research questions in Section 1.2, which are:

Question 4: In a drawing application, do users prefer manipulating a "fixed haptic" interface or its "variable haptic" counterpart?

Question 5: If a variable haptic design is preferred, do users prefer to manipulate it using an interface whose underlying haptic features mimics reality or is intuitive and creative?

The objective of this evaluation study is to test the effect of haptic metaphors on user haptic experience. In addressing this main idea, an investigation was conducted to find out the effect of both representations of the 'pen tools' metaphors, and the 'abstract haptic parameters' metaphor. This is done by examining the artists' subjective responses obtained from their haptic experience interacting with the drawing interfaces. The investigation involved checking artists' preferences of the interfaces with regards to the haptic sensation felt. The study findings will be presented based on the artists' positive and negative experiences. Towards the end of this chapter, a discussion pertaining to whether metaphors enhance or hinder user experience is presented. If the latter is the case, what recommendations should be suggested to overcome the problem? This section also highlights some reflections on generalisability of the results based upon the study findings.

7.2 Objectives of the Study

The objectives of the study are as follows:

1. *To test the effect of metaphors on users' haptic expectation*
2. *To test the effect of haptic metaphors on user experience*
3. *To investigate the user experience on the tactile sensation preferred*
4. *To examine the quality of haptic sensation for the interface that has pen tool and paper type metaphor whose underlying haptic parameter mimics reality*

These objectives were formulated to address the research questions stated in Section 7.1. Objective 1 is addressed in Section 7.5, Objective 2 in Sections 7.6 and 7.7, Objective 3 in Section 7.8, and finally Objective 4 in Section 7.9.

7.3 The Study

The objective of this section is to describe the participants involved in the evaluation study, the device and software employed, the interfaces to be evaluated, and the study design used. This includes the backgrounds of the artists that took part in the study, features of the fixed and variable haptic interfaces used in the study, and the method used to obtain the artists' responses.

7.3.1 Participants

Twenty-four traditional artists took part in the evaluation study (fourteen females and ten males). Seventeen of these artists were recruited among the arts students from the Slade School of Fine Art at University College London. Four of these artists were undergraduate students while the other thirteen were postgraduate scholars. All these students responded to the advertisement pertaining to the evaluation study, which was posted at the school notice board. The rest of the participants who took part were practising artists who paint for either a living or pleasure. These artists were introduced to the researcher by either those at the Slade School of Art who took part in the study or members of staff from the Computer Science Department at University College London. All artists were paid upon completion of the evaluation study.

7.3.2 Device and Software

The main haptic device used for interactions with the drawing application was the PHANToM desktop. The HapticDraw prototype was run on a Dell Latitude D600 notebook.

7.3.3 Materials

The graphical interface used in this study was the HapticDraw prototype as described in Chapter 6. The summary of these interfaces is as follows:

Interface 1

This interface adopts only the concept of visual appearance of the interface design described in Option A of Section 5.5.1. The interface consists of a real world object-based interface metaphor with the same haptic information for each pen-tool and paper type combination. (Refer Figure 6-6). The paper appearance and the line width change with the combinations chosen but the tactile sensation remains the same.

Interface 2

This interface follows the design concept of Option A described in Section 5.5.1. The Interface has the same design layout as Interface 1, and visual cues – i.e. paper appearance and line width produced as a result of the drawing interaction. (Refer Figure 6-6). However, each pen-tool and paper type combination has a different haptic feedback that mimics as closely as possible the sensation felt based on real world drawing interactions performed by a group of traditional artists in the study described in Chapter 3.

Interface 3

This interface follows the design concept of Option B described in Section 5.5.2. The interface has an abstract haptic description of an intuitive interface metaphor and a corresponding underlying haptic system. (Refer Figure 6-7). The user is able to change the parameter levels of "scratchiness", "bumpiness", and "stickiness" in order to get different haptic effects. The datasets in Interface 2 have been used as a foundation to design the haptic feedback in this interface but the sensation felt does not follow the real world tactile experience. The design layout is similar to Interfaces 1 and 2 but with different tool bars. The line width can be changed by choosing the options provided on the interface.

7.3.4 Study Design

The design of the evaluation study can be described in two parts which are: the briefing and training session, and evaluating the interfaces. A pilot study involving four artists was conducted to check the appropriateness of the study design.

Part 1: Briefing and Training

Before starting with the evaluation, all artists were briefed on the objectives of the study. (See Appendix 7-1 for a sample document). They were asked to sign a consent form to indicate they understood the purpose of the study and that their participation was fully voluntary. (See Appendix 7-2 for a sample Consent Form used).

The main objective of this training was to familiarise the artists with manipulating the PHANToM haptic device for drawing. All the artists involved in this study were first-time users of the PHANToM. The interface used in this training was the one that is used in the formative evaluation described in Section 6.4.3 but with adequate visual cues provided during the interaction. The artists were given about 10 to 15 minutes to interact using the interface. They had to make some free drawings or sketches on the interface. The artists had to try each texture and say out loud the tactile sensation felt during the interaction. The think aloud activity performed was a practice to verbally express different types of haptic cues from this texture discrimination exercise.

Part 2: Comparison Study

Within this part, two main comparisons are planned, which are comparing Interface 1 with Interfaces 2 and 3 and, comparing Interfaces 2 with 3. It is designed in such a manner so that the objectives of the study (Section 7.2) can be met.

The Interfaces

<u>Comparing Interface 1 with Interface 2 and Interface 3</u>

The main objective of this comparison study was to investigate the effect of metaphors of haptic sensation on user experience. This is to find out if the haptic information represented using the metaphor in the design is acceptable to the users.

<u>Comparing Interface 2 with Interface 3</u>

The primary objective of this comparison study was to investigate whether an object-based metaphor interface (Interface 2) is preferred to its abstract haptic description metaphor counterpart (Interface 3) when presenting the haptic cues. The other objective was to determine the most preferred haptic effects for a drawing interaction in Interfaces 2 and 3.

<u>Comparing Interfaces 1, 2 and 3</u>

This comparison study involved ranking the interfaces with respect to the user experience goal criteria as described by Preece et al (2002). The intention was to investigate any relationship between these three interfaces and with an established set of criteria.

Method

The evaluation study started by each individual artist drawing or sketching using the PHANToM and assessing the tactile sensation for each pen tool and paper type or haptic cues combinations on Interface 1 or 2, and Interface 3, respectively. They had to describe out loud the tactile sensation felt. The artists had to try all combinations on the interfaces in which the changing of these combinations from one to another was done by the researcher using a mouse. The artists were allowed to request for any combinations they wish to try again to confirm their judgement on the haptic sensation in this preference exercise.

In the study, 3 arbitrary task sets, called A, B, and C, which consist of an interface and a series of questions pertaining to the interface were used to facilitate discussion in this section. The task set determines the sequence of interfaces an artist had to follow. Task Set A consists of Interface 1 while B and C include Interfaces 2, and 3, respectively. The sequence of the task given to the evaluators was based on the controlled order design presented in Table 7-1. This design assists in providing a systematic approach to changing the order in which interfaces are experienced and ensures all sequences of interfaces are tested.

TABLE 7-1: TASK ORDERS USED IN THE STUDY

Artist No.	Task Set		
1, 7, 13, 19	A	B	C
2, 8, 14, 20	B	C	A
3, 9, 15, 21	C	A	B
4, 10, 16, 22	A	C	B
5, 11, 17, 23	C	B	A
6, 12, 18, 24	B	A	C

The series of questions in each task set are used during the debriefing sessions which took place after the artists' interactions with each interface. The questions focused mainly on the preferred haptic cues. After assessing an interface, the artist has to decide the pen tool and paper type or haptic cues combination(s) that they preferred based on the tactile sensation felt. When the first two interfaces have been evaluated, a question of preference between these two interfaces was asked and reasons for such choice. This provides an interim preference for the evaluation. Similarly, after the last interface was assessed, the artist had to decide their preference between the interface and the one they preferred during the interim evaluation. An example of these three task sets is presented in Appendix 7-3.

Using the case of Artists 1, 7, 13, and 19 in Table 7-1 as an example to illustrate the method used in this study, the sequence of events involved is described as follows.

The artists were given about 10 to 15 minutes to interact with Interface 1. They were asked to draw or sketch anything they liked on the interface. Free drawing or sketching was used in order not to limit the creativity of the artists. This was also to enable a generalisation of findings to be made rather than being too task-oriented. The artists tried all the pen tool and paper type combinations and described the tactile sensation felt during their interaction. They were allowed to speak freely about their tactile experience. After evaluating the interface, a debriefing session was conducted. The artists had to decide which combination(s) they preferred to interact with most and give reasons for this choice. Next the artists were given Interface 2 to evaluate. All procedures were replicated. Towards the end of the evaluation they were asked which of the two interfaces (i.e. Interface 1 or 2) they preferred to interact with in terms of the tactile sensation and why. At this stage the interim preference was obtained. Finally, the artists were given Interface 3 to evaluate; again, they had to try all combinations of cues available. The same steps when interacting with Interfaces 1 and 2 were followed. After the evaluation, the artists were asked for their preference between the previous interface that they preferred and Interface 3, and their reasons for this. This preference was used as the inferred final preference in the study.

Like the technique used in the study described in Chapter 3, this evaluation study only involved audio recording. No video recording to capture the artists' drawing interactions during the evaluation study was involved.

Overall Debrief

An overall debrief was conducted to rank the three interfaces based on the artist's preference in terms of the haptic feedback. User experience criteria based on Preece et al's (2002) criteria set were used for this debrief. (See Appendix 7-4). The individual ranking by the artists was used to check their consistency with the inferred final preference in the evaluation.

7.3.5 Data Treatment & Organisation of the Study Findings

The interviews were transcribed verbatim from the audio recordings, yielding twenty-four data sets. These were labelled according to artist reference number such as Artist 1, Artist 2 and so on. The study resulted in both quantitative and qualitative data. The quantitative data consists of the artists' preference towards the interface, and ranking of interfaces with respect to user experience goal criteria and tactile cues during the interaction, while the qualitative includes the articulated reasons for such preferences, vocabularies used to describe the tactile sensation in Interface 2, and any other remarks pertaining to the study that were voluntarily suggested by the artists during the evaluation. It should be noted that only a simple quantitative analysis such as counting the number of preferences was involved in this exercise. The main intention for this quantitative data is to provide a foundation for presenting the artists' subjective experience from the study. No statistical data was involved in the analysis since it is not the objective of the study to find the best out of the three interfaces evaluated. Qualitative findings whereby the reasons a particular haptic interface is preferred based on artists' perspectives provides a more appropriate assessment; this may limit generalisability of the study results.To be systematic in terms of presenting the study findings, the order of sequence of the study objectives stated in Section 7.2 is followed. In this case, the following six sections (i.e. Section 7.4 – Section 7.9) describe the study findings of the evaluation.

7.4 Interim and Inferred Final Preferences of Interfaces

This section reports the data treatment of the study findings that compare three different interfaces of the prototype. This analysis involves quantitative data.

TABLE 7-2: INTERIMS AND INFERRED FINAL PREFERENCE

Sequence of Interface	Artist	Interim Comparisons			Inferred Final Preference of 1, 2 & 3
		1 vs. 2	1 vs. 3	2 vs. 3	
1=>2=>3	1	2	-	-	
		-	-	3	3
	7	2	-	-	
		-	-	Both 2 & 3	Both 2 & 3
	13	2	-	-	
		-	-	3	3
	19	Both 1 & 2	-	-	
		-	-	3	3
2=>3=>1	2	-	-	2	
		2	-	-	2
	8	-	-	2	
		2	-	-	2
	14	-	-	2	
		Both 1 & 2	-	-	Both 1 & 2
	20	-	-	3	
		-	Both 1 & 3	-	Both 1 & 3
3=>1=>2	3	-	1	-	
		1	-	-	1
	9	-	3	-	
		-	-	3	3
	15	-	3	-	
		-	-	2	2
	21	-	1	-	
		2	-	-	2
1=>3=>2	4	-	3	-	
		-	-	3	3
	10	-	3	-	
		-	-	2	2
	16	-	3	-	
		-	-	3	3
	22	-	3	-	
		-	-	3	3
3=>2=>1	5	-	-	2	
		2	-	-	2
	11	-	-	Both 2 & 3	
		2	-	-	Both 2 & 3
	17	-	-	2	
		2	-	-	2
	23	-	-	2	
		2	-	-	2
2=>1=>3	6	2	-	-	
		-	-	3	3
	12	2	-	-	
		-	-	3	3
	18	1	-	-	
		-	1	-	1
	24	2	-	-	
		-	-	Both 2 & 3	Both 2 & 3

Table 7-2 shows a summary of artists' preferences of the three interfaces evaluated during the study. Within the main column labelled "Interim Comparisons" in Table 7-2, there are three columns that compare Interface 1 with 2, Interface 1 with 3, and Interface 2 with 3. For each artist, a two stages comparison was conducted in which the first phase is performed after two interfaces have been interacted with and the second is after the last interface has been tested. The decision made by the artists in the first interim comparison was taken into account when deciding for the second one. These two-stage comparisons correspond to the method described in Section 7.3.4.

From Table 7-2, the final preference of the artists, which is presented in the last column, was derived from an interim comparison that comprises all the three interfaces. This comparison process is necessary to assist artists in deciding the interface(s) they preferred to interact with and reasons for such choices. Such inferences were also useful for comparison with another set of data, which rank these three interfaces with respect to a set of user experience goal criteria. The intention is to check the consistency of both sets of data from the artist's responses. This comparison is presented in Section 7.7.

With the exception of study findings from Artist 11, the results obtained from all other artists in the second interim were directly considered as the most preferred interface(s) to interact with from the three options given. Such direct deduction can be easily made because the responses obtained from all these artists were quite straightforward in terms of the choices of their preferred interface. For example, Artist 1 interacted with the prototype using the sequence of Interface 1, 2, and 3 respectively. After interacting with Interface 2, he was asked for his preference of the two interfaces. His response was: "*Maybe 1? No, no. This one, 2, has sense of feeling even though some of them don't feel.*" This feedback also indicates the importance of conducting these interim comparisons, as artists sometimes get confused with the interfaces given to them. One of the reasons for such confusion could be of the same interface layout used in the case of the object-based metaphor interface. The response received from Artist 1 was used in the second interim comparison of interfaces. In this case, when asked for preference between Interface 2 and 3, Artist 1 chose 3 as his preferred interface. This decision is considered as the final preference of this artist and is noted in the last column in Table 7-2.

A slightly different deduction was made in Artist 11's final preference. In the case of Artist 11, responses from the first and second interim combinations were considered as the final preferences for this artist. During the first interim test, Artist 11 noted that he preferred both features in Interface 2 and 3. However, in the second interim test, which took place after interaction with Interface 1, Artist 11 expressed his preference of Interface 2 rather than 1. It was inferred that Artist 11 prefers both Interfaces 2 and 3 because of his earlier remarks during the first interim comparison on the reason he prefers these two interfaces. This decision is reflected in his final preference shown in Table 7-2.

It should be noted that in this evaluation task, i.e. in the period between the second interim comparison and the overall debrief session, the artists were not required to rank all the interfaces based on the tactile feedback. This has resulted in missing some data in terms of comparison between interfaces. For example, in the case of Artist 11, no comparison was made between Interfaces 1 and 3. However, this omission does not hinder the achievement of the objectives of the study.

7.4.1 Implications from the Inferred Final Preference

As shown in Table 7-2, nine artists preferred Interface 3, eight preferred Interface 2, three preferred Interfaces 2 and 3, two preferred Interface 1, one preferred Interfaces 1 and 2, and one preferred Interfaces 1 and 3. These findings show that twenty artists preferred either interface 2 or 3, or both of these, where the haptic metaphor is implemented. However two artists stated a preference for interface 1, where the haptic sensation remained unchanged.

The study findings indicated that a haptic metaphor linked to the suggested pen tool, as in Interface 2, or a haptic metaphor consistent with user control based on degree of bumpiness, scratchiness and stickiness, as in Interface 3, is preferable to Interface 1 where there is no haptic metaphor. It would seem in this case that artists prefer to interact with a drawing interface that corresponds to the haptic metaphor, as compared to those where the haptic sensation has not been designed to change and correspond to the suggested pen tool. The quantitative results show no clear preference between Interfaces 2 and 3. Such findings suggest a relevance of haptic cues for a drawing application and an effect of haptic metaphor on user expectation.

7.5 The Effect of Visual Metaphor on User Haptic Expectation

This section aims to address study objective 1 specified in Section 7.2.

From the study findings, the metaphor used to represent information for the real world object-based metaphor interfaces (i.e. Interfaces 1 and 2) have built an expectation of how the tactile sensation should feel when interacting using the pen tool on paper type combinations provided. The user experience expressed is in association with the actual pen tools that artists have used in the real world. For example, when interacting with Interface 1, Artist 8 said: *"If I click on charcoal I have this tool in my hand and this tool is I would imagine intended to simulate an artist holding a pen, holding this stick or paint. Then I would expect the charcoal to feel a bit like charcoal."*

The haptic feedback received enables the artists to relate the sensation perceived to those suggested by the metaphor. For example, when interacting with Interface 2, Artist 8 said: *"I recognise that the computer has an interpretation of the charcoal or something."* In another example using Interface 2, whilst Artist 6 tried to compare the tactile sensation between a 3H pencil and a 2B pencil on smooth paper, he said: *"Yes, so now I can relate back to that. So the resistance is actually relative to the 2B."*

Besides the expectation on the tactile sensation, the visual effect of the lines drawn was also expected to be similar to what was proposed by the metaphor. Artist 6 said: *"It is difficult to divorce your result from the tool. For me it is difficult to isolate using the tool from the image you want to create."*

Unlike the expectation of the metaphors used for both Interfaces 1 and 2, the study findings revealed that artists did not expect to obtain any particular haptic sensations or variation of lines drawn from the textual description metaphor interface (i.e. Interface 3). Artist 1 preferred Interface 3 because the interface metaphor used did not represent any particular drawing objects in the real world. With this type of design he did not expect or try to associate the tactile feedback with any specific drawing tools. He justified his preference for Interface 3 rather than 2 by saying: *"This one because it doesn't have a particular name like this pencil. If it has a particular name or pencil or ball-pen or something like that, I tend to compare with the real one. But because it has the general topic maybe scratchiness, bumpiness or something, yes, it's very general kind of feeling. I don't have to compare with the actual thing. That (pause) I prefer."* As to Interface 3, Artist 13 said: *"I would prefer this one. It is not pre-determined what you get. It's not pre-determined on the material you are going to use. You just say I want scratchiness like this, bumpiness (pause) that high whatever (pause) stickiness (pause) and you go, and you do and you just draw."* He commented on Interface 2 by saying: *"Where you would expect the same feeling as it says on the button or as you remember from the real world and if you don't get that you may not be satisfied with what you get."* There is an expectation that Interfaces 1 and 2 will produce haptic feedback that corresponds to the suggested metaphor i.e. pen tools and paper type on the interface.

7.6 The Effect of Haptic Metaphor on User Experience

This section aims to address study objective 2 specified in Section 7.2.

The artists' expectations built up from the metaphors used in the prototype led to both positive and negative haptic experiences. This section presents these experiences by segregating the two types of metaphors of haptic sensation, which are the real world object-based metaphor, and the abstract parameter metaphor, as follows.

7.6.1 Real World Object-based Metaphor

The Case of Interface 1

The quantitative data presented in Section 7.4.1 suggested that the majority of artists did not prefer Interface 1. The study findings revealed that Interface 1 did not meet the artists' expectations as the tactile sensation perceived did not match the metaphor suggested. Most artists commented that there is no difference in terms of the tactile sensation perceived from one pen-tool to another (Artists 4, 7, 8, 10, 11, 12, 13, 14, 15, 16, 20, 23, 24), and between the smooth and rough papers (Artists 1, 6, 9, 10, 17, 19, 24) in Interface 1. This is not what the artists had expected based on the metaphor suggested on the interface. For example:

Similarity of tactile sensation among the pen-tools:

> *"I don't think they are different."* – Artist 4, 'graphite pencil' and 'ball-point pen' on 'smooth paper'

Similarity of tactile sensation between the two papers:

> *"I think they are the same; in this space. Don't know why. The only difference between them is what we can see."* – Artist 1

Based on the artists' responses on Interface 1, their haptic experience in this section begins with their 'negative' experience followed by the 'positive'.

<u>Negative User Haptic Experience</u>

The fact that the haptic sensation felt the same throughout the interaction regardless of the pen-tool and paper type combination chosen created difficulties in assessing the haptic feedback to determine whether the haptic feedback perceived feels similar to that in the real world. In general, the artists only realised the type of drawing tool used when referring to the metaphor that represented the intended haptic information. This was expressed by Artist 13 who said: *"Most of them are hard to define which one is which. If I wouldn't see these (pause) er (pause) buttons of 3H pencil."*

The 'unexpected' haptic sensation as presented in Interface 1 also led to artists' preference towards Interface 2. It would seem that the metaphor used on the interface has little influence in convincing the artists. This is demonstrated in one example in the preference exercise. Artist 2 made a comparison between Interfaces 1 and 2, and expressed her preference for Interface 2, associating her fondness towards the feel of touch in the real world: *"They look identical but they feel different. Maybe because I am more of a 'material' person."* Such differences between the interfaces in terms of the 'material' feeling can be associated to the haptic textures of the interaction. This is in evidence from Artist 7 when she revealed her preference towards Interface 2: *"I prefer er (pause) I can feel the texture. It feels more like if you use different pencil, push it harder the feel is different. I mean the drawing interaction is different."*

Whilst stating his preference for Interface 2 as compared to 1, which was the task sequence, Artist 6 preferred a varying haptic sensation: *"I mean this, you don't get any impression there is any variation to the surface. I still prefer the other one."* Artist 24, whose task sequence and result of the first interim evaluation were the same as that of Artist 6, said: *"The first interface is better because I can feel the different surface of the paper, I can feel the different pen in my hand, I can feel the different smooth, the different paper between smooth paper and rough paper."*

In Interface 1, the assessment of the pen-tool and paper type combinations also resulted in various expressions used to describe the haptic feedback. This is mainly by relating the interface metaphor of the pen-tool on the interface to the artists' own tactile experience, not their expectations of the pen-tool metaphor. Artists expressed the tactile sensation perceived from Interface 1 as "*less resistance*" (Artists 8, 16, 23). They perceived such sensation as being "*smooth*" (Artists 1, 2, 3, 5, 6, 9, 16, 17, 18, 21, 22), "*loose*" (Artists 5, 21), "*slippery*" (Artists 5, 8), "*flat*" (Artists 16, 24), "*airy*" (Artist 16), and "*mercurial*" (Artist 16).

In other examples when there was a 'breakdown' in the metaphor, artists related Interface 1 to their own tactile experience and not specific pen tools. In some cases the smoothness sensation felt in Interface 1 was perceived as similar to a ball-point pen (Artists 1, 3, 8, 13, 18, 19, 21) or a 2B pencil (Artists 4, 18, 22) in the real world. For example, Artist 13 noted that the tactile sensation when assessing the ball-point pen on Interface 1 felt similar to the actual material in the real world: *"Pretty much the same feeling as material like ball-point."* He also perceived the roller-ball pen to have a similar tactile sensation to what he experienced when evaluating the ball-point pen: *"It's like ball-point pen."*

These were issues around control which may have led to a lack of preference for Interface 1. The tactile sensation of Interface 1, which is perceived as smooth and slippery, resulted in the artists not being able to control the drawing interaction (Artists 5, 16, 19, 22). For example, Artist 16 commented the interaction had no resistance and was difficult to control the drawing movement: *"There is no resistance at all. In fact if there is anything it is very light and airy. I find that not control, I can't control it."* Another example from Artist 22 who commented on the smooth sensation but difficulties in mark making: *"Smooth and fluid but not really (pause) er (pause) allowing too much control on the mark making."* This contrasts with Interface 2 with haptic feedback. In the case of Artist 5, when asked about her preference between Interfaces 2 and 1, she said: *"Definitely 2. Because 1, even though I like smooth surfaces and things like that, this one is too smooth, something smoother, loose, free flowing and there seems to be (pause) er (pause) I can't really control it. In 2, there seems to have a good balance between the controls, compared to 1."*

Positive User Haptic Experience

Despite being criticised for not reflecting the real world haptic sensation, Interface 1 was preferred by a few artists for its haptic feedback, creating a positive experience among some artists.

The smooth sensation has been perceived by some artists as being like a certain pen tool and paper combination or as pleasurable. This situation could be found in Artist 8's remarks when using a 'graphite pencil' on a 'smooth paper': *"It's quite nice. It has a nice bite to it."* In other cases whereby preferences of interfaces were involved, the haptic features of Interface 1 influenced artists' decision in their preference towards the interface although there is no variation in terms of the haptic feedback throughout the interaction. These could be identified in the responses made by Artists 3 and 18 whose final preference was Interface 1. For example, Artist 3 preferred Interface 1 because of the pleasure in drawing that she perceived: *"I think Interface 2 is a bit more similar to the real experience. There is some feeling that I found in both that I like, the smoothness and greasiness. Interface 1, rough paper, there is a lot of things that I like. I think Interface 1 'rough paper' is my favourite, in terms of pleasure."* From this remark, it appears that Artist 3 perceived the tactile sensation received from her interaction using 'smooth' and 'rough' papers as having different haptic feedback. This is not actually the case because only the appearance of the paper changes but the haptic feedback for Interface 1 remains the same. In this case, the changes of the paper appearance seem to have effected Artist 3's perception of the haptic sensation.

The smoothness feeling perceived has also led to a perception that the interface is easy to use for mark making as the sensation has resulted in a 'free flowing' of a drawing movement. In one example, Artist 20 noted that the haptic feedback for Interface 1 has an appropriate balance of the haptic dimension cues intended for it. He also stressed that for him the visual effect was more important than how the tactile sensation felt. With this argument he preferred Interface 1 to 2: *"I choose Interface 1 because in the sense that it is easy to work on this machine. Maybe the settings were just right for me. There is a good balance of scratchiness and a bit of stickiness everywhere whether it is '3H' or 'charcoal'. The sensation you get from the machine doesn't really make a difference."* This artist had used Interface 3 prior to Interface 1 and had been possibly alerted to the haptic parameter of stickiness. The order of task sequence may have influenced this artist's perspective.

The Case of Interface 2

Overall, Interface 1 was not preferred to Interfaces 2 and 3. This suggests that more positive experience could be identified from the artists' responses. In this case, the presentation of findings from the artists' haptic experience for both Interfaces 2 and 3 in this and the subsequent sections start with the 'positive' experience followed by the 'negative'.

Positive User Haptic Experience

The positive experience identified from the artists' responses when interacting Interface 2 are based on the haptic interaction being enjoyable, familiarity with the metaphor presented, the realism of the haptic sensation perceived, and the haptic feedback associated to artists' expressed feeling.

(i) An Enjoyable Haptic Interaction

The variation of haptic sensation with respect to the suggested visual metaphor displayed on the interface resulted in an enjoyable haptic interaction among the artists. In the case of Artist 11, he was fascinated by the fact that the physical pen-tool (i.e. PHANToM) is able to mimic various haptic effects of pens for drawing. When asked whether he preferred to interact with Interface 1 or 2, he replied: *"Definitely Interface 2! I think the whole is interesting. What provokes me to keep drawing is that if I can have different feelings (pause), really different feelings doing my drawing."* He further commented on the ability to use the device to replicate many pen-tools. He said: *"If I stick to the same tool but I got a different feedback come out from the same identical pen that would be like a magic pen!"* In another example, Artist 12, when comparing Interfaces 1 and 2, criticised Interface 1 by saying: *"This is for me it's just like two pens, two different pens just all about the graphics then on the Interface 2 because I got different feelings of the pressure on the pen so I'm feeling more er (pause) fun (laugh)."*

It would seem that such enjoyable haptic experiences may have motivated the artists in using the interface; also some of the haptic sensation seems to have triggered certain nostalgic memories. When using a crayon on smooth paper, Artist 6 said: *"I use to associate using a crayon with being a child so you (pause) whenever you use a crayon again you probably use it in the same (pause) I think it is difficult to break away from that mode of using certain tool. So the tendency is that the crayon you become sort of child-like. It may not be for everyone but I just having a crayon and just doing (pause) like you can see what I'm doing where drawing with a different thing and this is very similar to using a crayon but I wouldn't press it harder. I think with the other things about using a crayon is the tactile feedback you are using* *with such tool does, a kind of nostalgic satisfaction from it, maybe for me."* This association made by this artist is also parallelled by remarks made by Artist 23 who associated the tactile feeling of using crayon with a child-like interaction. She said: *"Again you kind of get this real waxy feeling like a crayon, quite bitty surface and (pause) Yeah. Because I also used crayon quite a lot (laugh) as well because I'm quite interested in a child (pause) and get that waxy (pause) quite "intimative" surface where you could press quite hard."*

(ii) Familiarity with the Visual Metaphor

The familiarity with the visual metaphor used to represent the underlying haptic information helped the artists in assessing the tactile sensation intended for the interface. The choice of the interface metaphor in Interface 2 is said to be appropriate as indicated in Artist 8's remarks: *"I still like the idea of being called 'charcoal'. It's very silly thing but (pause)"*. In relation to this quotation the metaphor used in Interface 2 has been described as easy to recognise. As Artist 8 emphasises: *"I quite like Interface 2 actually (pause) it makes me think because er (pause) because I recognise it more. When I use Photoshop er (pause) it has a kind of surfaces er (pause) you know you kind of get the charcoal cursor something I recognise that the computer has an interpretation of the charcoal or something. And I quite like it."*

The appearance of the pen-tools and paper type reminds the artists of the tactile feedback of the same drawing implements in the real world. The metaphor provided and the haptic feedback perceived as similar to the real world situation influences artists to prefer Interface 2. Artist 15, commenting on Interface 2, remarked: *"I like this because I can feel more. I can associate with more items. It's virtual but I can feel that I'm drawing with 'crayon', which is quite interesting how my mind associate with the virtual drawing."* This response indicates that despite being in a virtual world, this artist felt that the texture of the material could easily be associated with a real world situation and creates an interesting experience. Artist 23 also gave a similar reason that she could relate the tactile sensation from Interface 2 to her real world experience. She said: *"I prefer this one because you can kind of er (pause) I just feel that it is more real to life if I can relate it to my studio and I could get the options of using different er (pause) kind of surfaces in terms of paper and also in terms of tools (pause)."* To her the metaphor in Interface 2 is easy to remember as it has a close association to reality. She said that if the tactile sensation did not feel exactly the same as the real world that this did not bother her at all. Artist 23 said: "*'ball-point pens' (pause) how you see them then you (pause) it's not (pause) that (pause) too dissimilar (pause) it didn't quite er (pause) a real life impression (pause) that doesn't bother me too much."* It would seem that the haptic and visual metaphors support one another in Interface 2 and provide associations.

(iii) A Realistic Haptic Sensation Perceived

The realism of the tactile sensation as perceived by the artists was decided when they could feel the variation of surface textures with respect to the suggested visual metaphor during the evaluation study. The haptic feedback when using a combination of a pen-tool and paper type was said by an artist to be realistic if she perceived the sensation as being similar to that in the real world situation. In most cases, such realism leads towards an artist preferring certain type of interfaces. The evidence that a realistic tactile sensation perceived could influence artists' preference towards Interface 2 could be found in their responses. As an example, when comparing Interfaces 1 and 2, Artist 2 said that she preferred the latter because the tactile experience was more realistic than the former. In this case, Artist 2 quoted the tactile sensations of 'roller-ball' and 'felt-tip' pens to emphasise her preference towards Interface 2: *"I think this one is just much more realistic experience. The 'roller-ball' feels like roller-ball because it feels less sticky whereas the previous one (pause). Here, it is more different in using 'felt-tip' and 'roller-ball' but that one, there isn't."*

In general, the fact that Interface 1 is lacking in realism in terms of the tactile sensation made most artists prefer Interface 2 although both interfaces share the same visual metaphor. After interacting with interfaces in the sequence of Interfaces 2 then 1, Artist 8 expressed disappointment when he discovered the absence of the expected tactile feedback: *"Having gone through this process, it almost feels a bit disappointing not to feel the bite of charcoal."* Artist 13 noted the tactile sensation of the 'crayon' as realistic. Familiarity with the tactile sensation made him prefer Interface 2, instead of 1: *"I think the second interface is more realistic, in a way. Er (pause) in terms of the feeling in the real er (pause) materials. It feels (pause) because (pause) it stops as it should in a way. It stops because that's the nature of the material. It's different from graphite or pencils. The whole interface is more realistic than the first one."* Artist 15 also preferred Interface 2 because of the realistic sensation of 'crayon': *"I think (pause) I can feel crayon (pause)."*

Other than 'crayon', pen-tools such as 'charcoal' and 'graphite pencil' were cited by the artists when deciding their preference towards Interface 2 rather than 1. Artist 17 was given the task sequence in the order of Interfaces 2 then 1 said: *"With charcoal, it gives a different feeling and also with 'graphite pen' (pause) because now, 'charcoal' was really smooth in a way (pause) and is (pause) like the real thing."*

The reason for preferring Interface 2 because of its realistic sensation was also decided by the artists' general judgement towards the haptic feedback of the pen-tools and paper type combinations. Artist 21 who was given the task sequence in the order of Interface 1 and 2 noted that she strongly preferred Interface 2 because the tactile sensation of 1 felt the same regardless of the combinations selected: *"I definitely prefer this interface. But I like this* *because some of them are more successful on here than the other one. The first one all felt (pause). This one felt more like the real thing."* In another similar example, Artist 23 said that she preferred Interface 2 rather than 1 for being more realistic in terms of the tactile sensation perceived. The preference towards the variable haptic interface was also noted when Artist 1 said that Interface 2 has the sense of haptic texture: *" '2' has sense of feeling."*

(iv) Haptic Feedback and Expressed Feeling

The study findings revealed there is evidence from some artists' responses that haptic feedback is able to engage with their expressive feelings. According to Artist 1 whilst interacting with Interface 2, the tactile feedback is important for drawing because it connects with the expression of feeling. He said: *"Vibration is very important to draw because you can think of many things with feeling, expressing feeling."* This response indicates that tactile feedback received during a drawing interaction could be associated to the generation of ideas. Artist 11 said he could perform a drawing and sketching more efficiently: *"For me it's like I can do quickly with different kinds of feeling."* The importance of haptic feedback presented in Interface 2 is undeniable to the extent that the drawing interface is still preferred by the artists although a less than perfect haptic simulation is used. This artist preferred Interface 2 although it did not completely mimic reality. He said: *"For me the sensation would be really important and on this pen apart from I can't touch the screen I feel like er (pause) this pen is fulfilling. Well, only 40% what I would like to achieve for the reality"*

Negative User Haptic Experience

From the artists' responses a main negative factor identified for the user haptic experience when interacting with Interface 2 is regarding the difficulties in drawing lines.

When using Interface 2, some artists have developed an expectation of the drawing of lines being produced based on the visual metaphor suggested on the interface. For example, Artist 22 said: *"What I find is visually they are not corresponding necessarily to those materials. So then I would have to kind of learn that, and then discard it, because it wouldn't be useful to me."*

In another example, Artist 14 commented on the visual lines: *"Also, I would expect that when switching from 3H pencil to 2B pencil you would get a different line. So, the impression is I'm getting the same quantity of mark."* She also commented on the haptic feedback based on the pressure she applied when drawing using the interface. She said: *"When you push the pen down the paper, this has to get feedback in there, not moving. But when you get moving that is fine. When you stop, still you get the quantitative feedback."* This is a limitation in terms of the haptic feedback being provided when the pen is static in the prototype. Artist 19 was mindful about Interface 2 needing more effort to draw a line as compared to Interface 1, which is easier in terms of the mark making. This influenced him to choose both Interface 1 and 2 as an interim choice: *"First one. Er (pause) easier. I get lines together (pause) I want."*

7.6.2 Abstract Parameters Metaphor

The Case of Interface 3

<u>Positive User Haptic Experience</u>

From the artists' responses, the positive experience with respect to the effect of metaphor could be presented mainly based on the direct and interesting experimentations when controlling the visual and haptic parameters provided on the interface.

(i) Direct User Control of Haptic Parameters

The study findings revealed that the user sense of control of haptic feedback and the visual metaphor displayed on the interface creates a positive experience amongst the artists. In terms of the generic labels that represent the haptic information in Interface 3, Artist 12 thought that this metaphor was acceptable for the design. When expressing her preference for Interface 3, she said: *"I prefer this one. Because I don't think the names that apply on the pen are actually matched with the thing that I'm drawing. So, I prefer just turning to what actually I can choose."* In another example, Artist 9 commented on the irrelevance of the pen-tools labelling in the interface because she could easily understand the haptic dimension cues combinations in Interface 3. She said: *"Because I don't think I need to refer to things like a '3H pencil', '2B pencil' because you might pick up (pause) the variety of 3-2-3."*

The three parameter levels to manipulate the degree of scratchiness, two levels for bumpiness and three for stickiness allowed the artists to directly control the amount of haptic feedback during the drawing interaction. Artist 10, who did the task sequence of Interface 1 then 3, said: *"This one, I prefer. This one I can control right, how I want to do it."* This indicates freedom to set one's own haptic feedback within the parameters as required.

In a similar example, Artist 4 preferred Interface 3: *"Number 3. I know number 2 much better than number 1. But number 3, I can adjust the scratchiness, bumpiness and stickiness to suit me."* Artist 16 strongly asserted his criteria of preference, based on the haptic features in Interface 3. He said: *"I really want everything. I want to control. I want as many options as possible, to play with the textures (pause) very resistance you can't make that complete (pause) you can't control the line as well (pause) Er (pause) I prefer that possibility."*

The visual metaphor in terms of the haptic parameters that represent the haptic information on Interface 3 has also allowed the artists to develop their preference towards certain haptic cue combinations when determining the interface that they prefer to interact with. When evaluating Interface 3, Artist 19 said: *"First one wasn't that good the third one, the 'medium-low-low' I like the idea of being (pause) I don't know (pause) I just like that 'medium-low-low' thing. I think this is better (pause) that called scratchiness (pause) because I can set the pressure I want to draw rather than imitate a kind of material I want."*

(ii) User Control of Visual Parameters

As with Interface 2, some artists expressed their fondness for the lines drawn. Besides preferring Interface 3 for the way the tactile feedback is presented, Artist 22 likes the option of changing the line width on the interface. She said: *"I like an option of changing the line width on this interface (pause) because that is (pause) drawing; to me it is about changing the mark."* Artist 22 may be signalling her expectation that the interface will be similar to other commercial drawing computer applications in terms of the visual feedback that she may have experienced before.

In another example pertaining to the line drawn in Interface 3, Artist 16 commented on the feature of changing the line width using a mouse while at the same time getting the tactile sensation from the PHANToM. In this case, the tactile feedback was set at 'high' scratchiness, 'high' bumpiness, and 'high' stickiness and the line thickness alternated between thin and thick. He said: *"That's kind of nice because you can use both hands for that. That's the kind of varying. Completely different. I could gradually click it half through the line. That's quite nice. It feels that sort of again a random clicking going on. That's I like. I would love the thickness of the line and just be tapping away with your left hand creating a thickness of lines."* The remark indicates Artist 16's interest in experimenting with the line width when a fixed haptic sensation is set for Interface 3. This condition has a similar concept to Interface 1 in terms of variation of visual lines on a fixed haptic feedback but using an interface design whose interface metaphor adopts the "appearance" of Interface 3.

(iii) Interesting Experimentations on Parameters

The metaphor for Interface 3 that allows direct manipulation of the parameters makes the haptic interaction more interesting as artists could experiment with the haptic feedback. Artist 20 preferred Interface 3 to Interface 2. He said: "*When you sort of play around with the variables you kind of get that better feel of the machine as in like (pause). There is so much more you can achieve here than there (pause) because for this you can switch around and you* *can get either a very sensitive drawing or a very graphical drawing, very harsh drawing, very soft drawing."*

Artist 16 preferred Interface 3 to Interface 1 because of the feel of different textures generated by the PHANToM that he could experiment with: *"This one. It is more interesting (pause) because you can feel the difference of textures. Interesting in terms of it feels that it's more experiment, the computer's able to generate this thing. The last one, the lines just changed, everything else is the same, whereas this one, the line is the same and the textures, the underlying texture is different. So it's the opposite of that."*

Artist 9 associated an interaction using Interface 1 with that of using a mouse. Using the task sequence of Interface 3, then 1, she preferred Interface 3. She commented about Interface 1: *"Using a mouse probably would be as the same with this without tactile sensation."*

The possibility of controlling the haptic feedback seems to be making an interaction more interesting. Artist 6 said: *"This one, I like the stickiness more. I would want to play with that. I do like the extremes like the stickiness. I can't think of the reality the way you would be able to mimic those resistance so therefore I probably want more variety of it to try to make to experience drawing in a different way. This is quite an interesting thing. Obviously end up making things with it but the technique is interesting. And it offers thing that you know the options like stickiness that you would get from formal media, you know materials available to use. So it wants to make me find something equivalent to stickiness to draw on. I don't know of what it would be."* This quotation shows that the new tactile feedback experienced has prompted him to prefer the creation of underlying haptic feedback for a drawing interaction. He stressed that, with the help of existing technology, haptic information should be represented in such a way that the feedback could be experienced beyond 'reality'. He said: *"Just simply because the potential is there with the computer to create the extreme that you can't in reality."* He stressed that his preference was due to *"experience drawing in a different way."* To him mimicking reality may not always be necessary: *"media not necessary thing to create an end point."* The remarks made by Artist 6 show that an additional feature in terms of haptic feedback for a drawing application that is not available in the real world could be highly acceptable to users.

In some cases, artists in the evaluation study preferred a haptic sensation that mimics reality, others did not. Artist 23 expressed an element of freedom with Interface 3: *"I think it's just make you feel more er (pause) freer (pause) less constraint er (pause) and being more like a child (pause) because I'm quite interested in a child (pause) very much in what a child draw er (pause) and the whole idea of what they use pencils and all the scrappiness pressure er (pause) but generally it allows artists to be freer and be more creative."*

Negative User Haptic Experience

Based on the artists' responses, a main drawback in Interface 3 that led to a negative experience is the complexity of the metaphor used to represent haptic feedback.

Alternatives have been offered for the visual metaphor used to represent haptic information for Interface 3. Artists tend to contrast the two other interfaces (i.e. Interfaces 1 and 2) which have the pen tools and paper type names as their visual metaphor with the visual haptic parameter in Interface 3. Artist 18 is in favour of a metaphor that closely represents drawing tools. *"I prefer to have the pencils."* She went on to comment about the existing format. *"Probably this could be the feature on the pencils. But I think this is too much information we don't need that."* Artist 21 chose Interface 1 when asked which of the two interfaces, i.e. Interface 1 and 3, she prefers: *"I like the way that I can click on 'ball-point pen' for example and get the sensation that I know (pause) making a mark like a 'ball-point pen'."*

Artist 2, preferred Interface 2 and had no problem with the interface metaphor used and its underlying haptic feedback. She found the metaphor used in Interface 3 difficult to comprehend as she tried to relate the haptic experience to the real world drawing interaction: *"I like the second one, the one with the smooth and rough paper. I think the ability of changing the smooth paper and rough paper so you can decide. While this one you have your own whereas I prefer the paper one because it feels the paper more. This to me is what does this mean? material and pencil tools?"* Artist 4 suggested that thinking about the haptic parameters directly may be problematic and stated her preference for Interface 2: *"I don't have to think about what scratchiness means, what bumpiness means, what stickiness means."*

Artists 10 expressed a reason for favouring Interface 2 rather than 3: *"I think probably 2 because it's easier to remember how it felt whereas 3 is different combinations which is quite confusing. It's difficult to tell what it is doing."* Artist 17 preferred Interface 2 rather than 3. *"I think this one because it gives easier feeling. In this thing it's like you know what you are doing. That one is just a different experience, really."*

Artist 5 also preferred Interface 2 to 3: *"With this one there is a set of number of choices that I can make and the tools that I can use. That one, there seems like there are so many possibilities and I might miss one or I might get too complicated. For me even though in a way that one can have more control. It seems that if I want to go back if I like the crayon I can remember that rather than low-low-high."* She preferred Interface 2 but offered an adaptation for using Interface 3 as to a facility to remember the combinations of haptic cues preferred. She said: *"If there is an easy way to remember or 'low-low-high' is a nice one, make it as a tool, create a tool, I mean Interface 3."*

Artist 18 commenting on Interface 3: "*I have to evaluate what I want by trial. I cannot understand what is 'scratchiness' and I cannot understand what is 'bumpiness' unless I try (pause) but in my mind I have learnt that specific tools have specific features. So it's easy for me to select the tools and the features. I could do like that (pause) but it's more complicated.*"

The findings revealed that Interface 3 is not always preferred and the reason seemed to be based on the haptic parameters metaphor being less definitive as compared to Interfaces 1 and 2.

7.7 User Experience Criteria Preferences of Interfaces

In Section 7.4.1, it was revealed that the number of artists who preferred each of Interfaces 2 and 3 was larger than Interface 1. The finding was followed by an analysis based upon the artists' responses on how the effect of haptic metaphor implemented for each interface has an influence on the user experience.

This section continues the study analysis by examining the final interface preference for each artist with their responses on the ranking of the three interfaces based on a set of user experience goal criteria. The objective of this analysis is to investigate the consistency of results from such examination with those obtained from the artists' final preference in Table 7-2. It is also to find out if there is any association between these generic criteria and the effect of haptic metaphor on user experience presented in Section 7.4.3.

7.7.1 Data Treatment for Ranking of Interfaces – Stage 1

The analysis starts by examining the ranking of interfaces that each artist scored with respect to the user goal criteria. Two examples of such ranking are presented in Table 7-3.

TABLE 7-3: RANKING OF INTERFACES - THE CASE OF ARTISTS 1 AND 2

Artist: 1			
User Experience Goal	Preference		
	Least ==> Most		
Fun	1	2	3
Emotionally Fulfilling	1	2 & 3	
Rewarding	1 & 2 & 3		
Supportive of Creativity	1	2 & 3	
Aesthetically Pleasing	1 & 2 & 3		
Motivating	1	2	3
Helpful	1 & 2 & 3		
Entertaining	1	2 & 3	
Enjoyable	1	2 & 3	
Satisfying	1 & 2		3
Interface 3 => 3 Interface 2&3 => 4 Interface 1&2&3 => 3			

Artist: 2			
User Experience Goal	Preference		
	Least ==> Most		
Fun	1	3	2
Emotionally Fulfilling	1	3	2
Rewarding	1	3	2
Supportive of Creativity	1	2	3
Aesthetically Pleasing	1	3	2
Motivating	3	1	2
Helpful	3	1	2
Entertaining	1	3	2
Enjoyable	1	3	2
Satisfying	1	3	2
Interface 2 => 9 Interface 3 => 1			

Table 7-3 shows the responses obtained from Artists 1 and 2 on their ranking of the three interfaces. The number of times each interface has been rated as the most preferred with respect to each criterion were counted and summarised at the end of the ranking for each respective artist. The interface(s) that was chosen as the preferred choice indicated in the final preference obtained from Table 7-2 is highlighted in bold. For example Interface 3 was preferred based on the overall final preference for Artist 1 while Interface 2 was for Artist 2.

A similar technique was used in treating the data for each artist and her/his preference for both the final choice and the ranking of interfaces based on the ten criteria. A full set of information as presented in Table 7-3 that contains each artist is appended in Appendix 7-5.

7.7.2 Data Treatment for Ranking of Interfaces – Stage 2

Before determining whether the artists were consistent in their responses or not, a second stage of data treatment was performed. In this stage, the score for each preference of an interface was given in order to facilitate a graphical representation of the data for analysis. A simple measuring technique was used in which a point is given to an interface for each time it was rated the most preferred with respect to the user experience goal criteria. In a case whereby two interfaces were rated as the highest they share an equal of 1/2 mark for each. Similarly, if three interfaces were involved, 1/3 will be allocated to each interface.

Using Table 7-3 as an example to demonstrate this technique, in the case of Artist 1, he scored point (10%) for Interface 1, 3 point (30%) for Interface 2, and 6.0 points (60%) for Interface 3. Likewise, Artist 2 scored 0 point (0%) for Interface 1, 9 points (90%) for Interface 2, and 1 point (10%) for Interface 3. A similar technique was applied to the rest of the artists' responses in the study. A complete table containing the information of these percentages from all the 24 artists is appended in Appendix 7-6.

7.7.3 Checking for Consistency of Response

The percentages information as described in the simple scoring technique was presented graphically to facilitate the checking for consistency of the responses. An example of such graphical representation is shown in Figure 7-1.

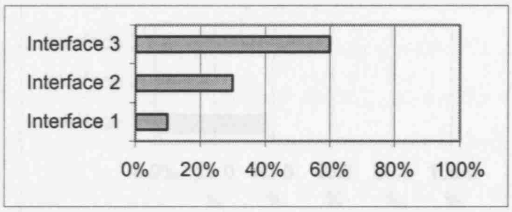
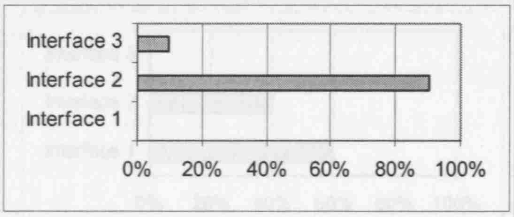
Artist No.	Inferred Final Preference		Consistency Checklist [√ => Consistent; X => NOT consistent]
1	3		√
2	2		√

FIGURE 7-1: CHECKING CONSISTENCY – THE CASE OF ARTISTS 1 AND 2

Figure 7-1 presents a bar graph pertaining to Artists 1 and 2's ratings of the three interfaces based on the user experience goal criteria. An artist is said to be consistent in their preference towards a particular interface if their highest bar graph matches the associated inferred final preference. In the case of Artist 1, his responses were considered as consistent because the highest bar (60%), which corresponds to Interface 3 matches his inferred final preference of interfaces. The example from Artist 2 was more straightforward as the bar graph of Interface 2 about perfectly matches her inferred final preference.

The same process in presenting the graphical information on artists' preferences was replicated with the rest of the data. A complete set of information containing these bar graphs is Appendix 7-7. Each artist was checked on the consistency of their responses towards the preferred interface. In each case, a 'tick' is given for a consistent response and a 'cross' for inconsistent.

The data analysis revealed that most of the artists were consistent in their preference towards a particular interface i.e., both the highest interface(s) ranked with regard to the user experience goal criteria, and the inferred final preference match one another. However, three artists were found to be less consistent in their judgement. For discussion purposes, the graphical representation of the data information for these artists is presented in Figure 7-2.

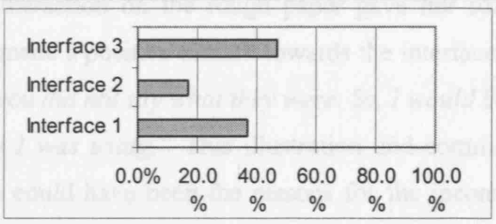
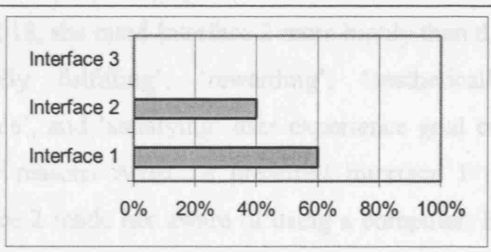
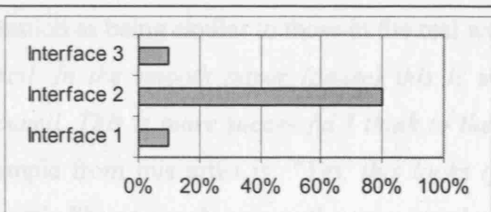
<table>
<tr><th>Artist No.</th><th>Inferred Final Preference</th><th></th><th>Consistency Checklist [√ => Consistent; X => NOT consistent]</th></tr>
<tr><td>3</td><td>1</td><td>
</td><td>X</td></tr>
<tr><td>8</td><td>2</td><td>
</td><td>X</td></tr>
<tr><td>18</td><td>1</td><td>
</td><td>X</td></tr>
</table>

FIGURE 7-2: THE INCONSISTENT CASES

From Figure 7-2, Artists 3 and 18 whose inferred final preference was Interface 1 were considered as not being consistent because the highest bar graphs for each indicate Interfaces 3 and 2, respectively. Artist 3 rated Interface 1 as better than Interfaces 2 and 3 only for the 'aesthetically pleasing', and 'satisfying' criteria whereas Artist 18 was just on the 'support creativity' criterion.

In the case of Artist 3, she rated Interface 3 more highly than the other two interfaces for 'fun', 'emotionally fulfilling', and 'supportive of creativity' user experience goal criteria. When evaluating the haptic sensation of this interface, Artist 3 used a lot of association between the haptic feedback perceived with her previous tactile experience in the real world. For example, when trying the 'high' scratchiness, 'high' bumpiness, and 'high' stickiness combination: *"It's like carving something. Like a stone with a stone."* A similar remark was made when she tried the 'high' scratchiness, 'high' bumpiness, and 'medium' stickiness combination: *"I think this is interesting. It's very graphic. It's like some etching, some painting technique that you have to scratch (pause) when you have to scratch with something er (pause) a metal. Like engraving."*

Perhaps, the fact that the haptic feedback when interacting with Interface 3 enabled Artist 3 to perceive that she was "making something" influenced her decision when rating the three interfaces against the user experience goal criteria. Even though Artist 3 preferred Interface 1 on the basis that the interaction on the rough paper gave her some pleasure in terms of drawing on it, she also made a positive remark towards the interface metaphor of Interface 3. She said: *"Interface 3, you did not say what they were. So, I would be more freely to try it out without bothering what I was using."* This illustration and comments made on the haptic feedback of Interface 3 could have been the reasons for the inconsistency of preference in Artist 3's judgement.

In the case of Artist 18, she rated Interface 2 more highly than the other two interfaces for the 'fun', 'emotionally fulfilling', 'rewarding', 'aesthetically pleasing', 'helpful', 'entertaining', 'enjoyable', and 'satisfying' user experience goal criteria. From the inferred preference, one of the reasons Artist 18 preferred Interface 1 rather than 2 is because interacting with Interface 2 made her aware of using a computer. However, she commented that there were a few kinds of haptic feedback from Interface 2 that she preferred because she perceived the haptic sensation as being similar to those in the real world. She said: *"This feels exactly like the 2B pencil. In the smooth paper (pause) this is more realistic to the real sensation than the 3H pencil. This is more successful I think to the (pause) yes, it's like the real one."* Another example from this artist is: *"Yes, this looks (pause) feels like crayon. Perhaps doesn't look exactly like crayon in a smooth paper but the feel is like crayon."* This haptic experience could be a reason Artist 18 has been inconsistent in her preference towards the three interfaces.

Artist 8 is another evaluator who was considered as not being consistent in his preference. Interface 2 was inferred to be his final interface preferred but Interface 1 was indicated as the best from his rating. When assessing the haptic feedback for Interface 1, Artist 8 noted that there is no difference between one pen-tool to another. For example, after trying 'crayon' and 'charcoal' on 'smooth paper', he said: *"It doesn't. To be honest it doesn't feel awfully different."* During the final debrief, Artist 8 confirmed his preference towards Interface 2 for the reason of the tactile feedback that reflects the pen-tool in question.

In the case of Artist 8, a possible reason for the inconsistency of his preference could be due to the same appearance of Interfaces 1 and 2. The interface metaphor used and the visual cues provided for a particular pen-tool and paper type combination may have suggested the tactile sensation of the drawing interaction. Such pre-conceived perception could have influenced and biased the artist's judgement. This claim could be supported when Artist 8 said: *"I think the lines are (pause) you know, thicker for the charcoal. It gives me the impression of charcoal but really the pen they all feel so similar at the moment. Er (pause) and I mean it feels very, very maybe there is a little bit more bite in it or grit."* Such opinions from Artist 8 towards Interface 1 could have influenced him to rate this interface higher than Interface 2 for the 'emotionally fulfilling', 'rewarding', 'aesthetically pleasing', 'helpful', 'entertaining', and 'enjoyable'. The remaining 21 participants showed consistency in their overall ratings and their ratings against the 10 user experience criteria.

7.7.4 User Experience Goal Criteria and the Interface Evaluated

This section examines further, which of the user experience goal criteria could be supported by the three interfaces. In conducting this analysis, the number of times an interface or a combination of interfaces was rated as the most preferred with regard to a particular criterion was counted. This was carried out for all ten criteria. A graphical representation of this information is presented in Figure 7-3.

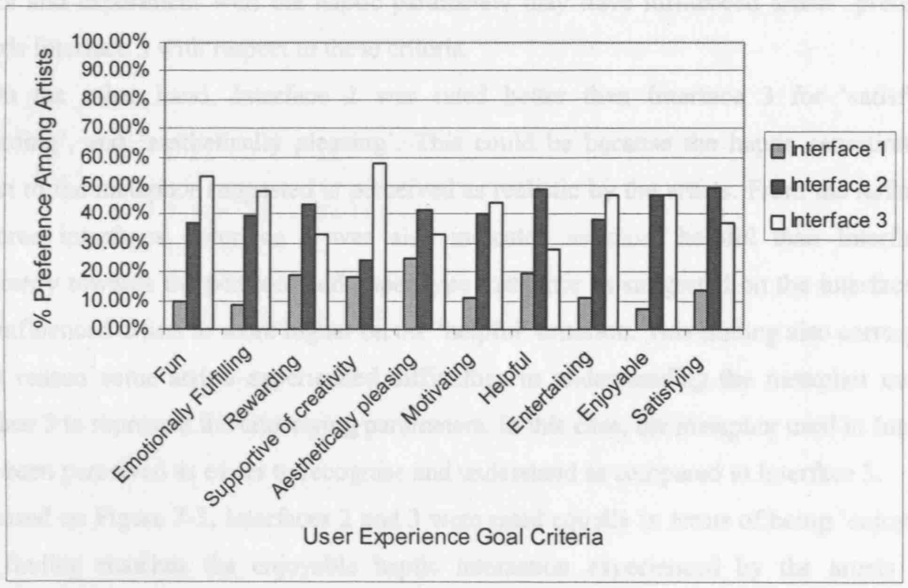


FIGURE 7-3: PERCENTAGES OF PREFERENCE AMONG ARTISTS VS. USER EXPERIENCE GOAL CRITERIA

Figure 7-3 shows the percentages of scores obtained from the artists' preferences towards a particular interface with respect to the set of user experience goal criteria. From the sample of 24 artists, both Interfaces 2 and 3 were consistently rated higher than Interface 1 for each criterion. This indicates that Interface 1, which has no designed haptic metaphor in association with the visual pen tool metaphor suggested on the interface, was not in favour when being assessed against the user experience goal criteria. This finding is consistent with the study result in Section 7.4.1 that indicates the majority of artists preferred to interact with a drawing interface that corresponds to the haptic metaphor, as compared to those where the haptic sensation has not been designed to change and correspond to the suggested pen tool.

The Ranked Interfaces and the Effect of Metaphor on User Experience

As shown in Figure 7-3, within the sample of 24 artists Interface 3 scored better than the other interfaces on the 'supportive of creativity' criterion. This finding corresponds to artists' subjective experience when interacting with the interface whereby they felt that the haptic feedback perceived could engage expressive feelings as presented in Section 7.4.3. One of the reasons this criterion scored better for Interface 3 could be because the interface allows the artists to directly control the haptic parameters in order to create ones own media (Artist 8). This interface was also rated better than Interface 2 for the 'fun', 'emotionally fulfilling', 'entertaining', and 'motivating' criteria. Again, the options provided on the interface to control and experiment with the haptic parameters may have influenced artists' preference towards Interface 3 with respect to these criteria.

On the other hand, Interface 2 was rated better than Interface 3 for 'satisfying', 'rewarding', and 'aesthetically pleasing'. This could be because the haptic sensation with respect to the metaphor suggested is perceived as realistic by the artists. From the ranking of the three interfaces, Interface 2 was also indicated as more helpful than Interface 3. Familiarity towards the pen tool and paper type metaphor as suggested on the interface may have influenced artists to score higher on the 'helpful' criterion. This finding also corresponds to the reason some artists experienced difficulties in understanding the metaphor used on Interface 3 to represent the underlying parameters. In this case, the metaphor used in Interface 2 has been perceived as easier to recognise and understand as compared to Interface 3.

Based on Figure 7-3, Interfaces 2 and 3 were rated equally in terms of being 'enjoyable'. This finding matches the enjoyable haptic interaction experienced by the artists when interacting with Interface 2 presented in Section 7.4.3. In the case of Interface 3, the enjoyable feature could have resulted from the artists' experiences in controlling, and experimenting with the haptic parameters to obtain the haptic feedback they like.

7.8 Artists' Preferred Experience of Haptic Sensation

In Section 7.6, the effect of haptic metaphor has resulted in some positive experiences among the artists. This experience is examined further in this section by determining the artists' preferences of the haptic sensation represented using the pen tools and paper type in Interface 2 and the dimension cues (i.e. scratchiness, bumpiness, and stickiness) in Interface 3. The aim is to address study objective 3 stated in Section 7.2 which is to investigate the user experience on the tactile sensation preferred. The purpose is to understand the features of haptic sensation preferable for a drawing interaction.

7.8.1 Preference for Haptic Cues in Interface 2

This sub-section presents the study findings pertaining to the preferred pen-tools and paper type combinations that artists preferred to interact with in terms of the tactile feedback. The patterns observed from the findings are used to determine the haptic cues preferred in a drawing interaction. During the evaluation study, each artist could state as many preferences for pen tool and paper type combinations as they wanted. This was plotted on a bar graph shown in Figure 7-4.

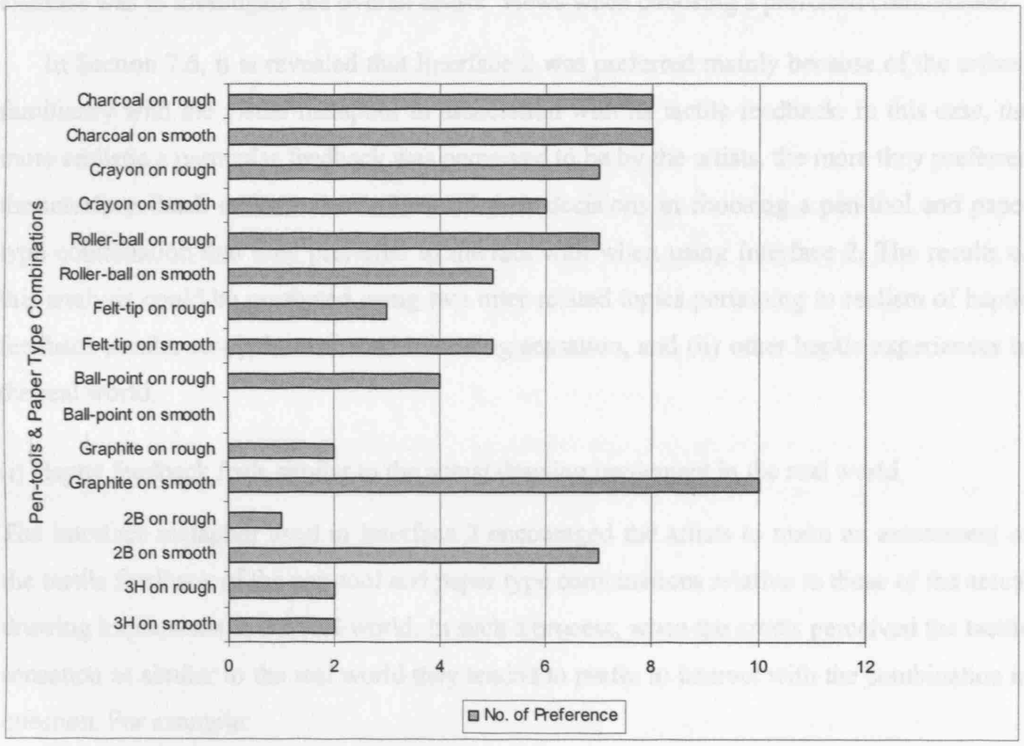


FIGURE 7-4: PREFERENCE FOR PEN-TOOLS AND PAPER TYPE COMBINATIONS

Figure 7-4 shows the total number of artists' preferences with respect to particular pen tool and paper type combinations. The highest score, which corresponds to the 'graphite pencil' on 'smooth paper', signals the preferred pen tool and paper type combinations. The lowest score corresponds to the 'ball-point pen' on 'smooth paper'. The scattered distributions of the artists' preferences towards the pen-tools and paper type combinations imply that none of these combinations is dominating the artists' preference. It is the overall preference of the interface and not an individual pen tool combination that is determining the choice.

The fact that 'ball-point pen' on 'smooth paper' was not preferred by the artists could be because the haptic sensation did not meet the artists' expectations. Artist 6 described the interaction using a 'ballpoint pen' on 'smooth paper' as *"a pen, which is stuck with ink"*. Artist 12 provided a similar comment, which says: *"feels like the ink is going to finish"*. From these two responses, it could be deduced that the interaction perceived still feels similar to the real world but not in an ideal situation. Rather, the sensation felt and described was based on these artists' previous experience interacting with a similar implement in the real world.

Artists' Perspectives on Reasons for Pen-tools and Paper Type Preferences

The responses from the artists presented in Figure 7-4 in terms of the haptic feedback of the pen-tool and paper type combinations that they prefer to interact with were examined. This exercise was to investigate the overall artists' views when choosing a preferred combination.

In Section 7.6, it is revealed that Interface 2 was preferred mainly because of the artists' familiarity with the visual metaphor in association with its tactile feedback. In this case, the more realistic a particular feedback was perceived to be by the artists, the more they preferred the interface. Such realism also influenced their decisions in choosing a pen-tool and paper type combination that they preferred to interact with when using Interface 2. The results of this analysis could be presented using two inter-related topics pertaining to realism of haptic feedback similar to (i) the real world drawing sensation, and (ii) other haptic experiences in the real world.

(i) Haptic feedback feels similar to the actual drawing implement in the real world

The interface metaphor used in Interface 2 encouraged the artists to make an assessment of the tactile feedback of the pen-tool and paper type combinations relative to those of the actual drawing implements in the real world. In such a process, when the artists perceived the tactile sensation as similar to the real world they tended to prefer to interact with the combination in question. For example:

> *"That's the feel for 2B."* – Artist 13, '2B' on 'smooth paper'
>
> *"This is close to the actual feeling, the smoothness, the feeling of drawing."* – Artist 15, 'felt-tip pen' on 'smooth paper'
>
> *"Roller-ball pen. Yes, this is success. Yes."* – Artist 18, 'Roller-ball' on 'rough paper'
>
> *"I think charcoal, the graphite pencil, the 2B pencil, they do definitely resemble the type of friction resistance."* – Artist 9, '2B pencil', 'graphite pencil', and 'charcoal' on 'smooth paper'
>
> *"Crayon is interesting feeling. And then ... I think is quite similar. I like it."* – Artist 11, 'Crayon' on 'smooth paper'

> *"Ok. That's the charcoal that I think that is supposed feel like charcoal."* - Artist 9, 'Charcoal' on 'rough paper'

(ii) Haptic feedback feels like interacting using a different drawing medium

With respect to the realism of haptic feedback perceived when using Interface 2, several artists felt that the tactile sensation may not necessarily feel similar to the actual interaction using the respective pen-tool and paper type in the real world. However, such a difference did not prevent them from preferring the combinations in question. For example, Artist 1 who preferred a '3H pencil' and a 'ball-point pen' on 'rough paper' said: *"3H pencil on a rough paper and ballpoint pen. I think the texture is fine so far. Because its response is a little bit different from what I intend."*

Despite receiving an unusual tactile sensation compared to the real world, Artist 8 thought the feedback was interesting because he perceived such an interaction in an unconventional way. His comment when using a ball-point pen on rough paper: *"I find it's interesting, actually. I am kind of interested in this ball-point pen. Maybe because it is non-orthodox."* Artist 11 also preferred the tactile sensation of 'ball-point pen' on 'rough paper'. Whilst confirming his preference, he said: *"Ball-point pen, ok. The motor is really, active."*

While most artists did not specifically describe how the haptic feedback felt in association with the actual pen-tool and paper type in the real world, a few of the artists explicitly expressed their new haptic experiences as interaction using a different drawing medium. When using a '3H pencil' on 'smooth' and 'rough' paper, Artist 1 expressed: *"I feel like drawing on cardboard. Not on paper. Like scratching."*

Artist 1's perception on the type of drawing surface used was echoed by Artist 18, who commented on the texture of the 'rough paper'. According to Artist 18, the tactile sensation for 'ball-point pen' on 'rough paper' felt like using very rough paper. She preferred the tactile sensation regardless of the haptic experience perceived. *"Yes, and I like that too actually. Yes, ball-point pen (pause) this realistic (pause) also on rough paper because you don't have the possibilities to run very fast with the ball-point pen on the very thick paper. Also this paper has (pause) the established rough paper is quite thick paper. I'm feeling it as a thick, very rough paper. It's not a medium rough paper. It's thick enough and very rough."*

While Artist 18 said that the paper used when interacting using a 'ball-point pen' on 'rough paper' felt *"very thick"* and *"rough"*, Artist 5 thought the 'smooth paper' felt like a "*shiny surface*" when she used it with a 'felt-tip pen': *"It's like the line is stickier. Its line kind of stays there. It's not rubbery. It's more kind of slippery. Like, like a felt-tip pen. I would say even on not on paper but on a shiny surface. So, like the board. Like the whiteboard in the university. So, this is exactly what it feels."*

Artist 22 perceived the feeling of a pen on a whiteboard when she tried the 'charcoal' on 'rough paper'. "*That feels like an eraser on a marker board.*" She further reflected on this sensation: "*I mean, a pen on a white board. But it is very nice. It is quite fluid.*"

Artist 11 thought that rough paper used in combination with 'crayon' felt like 'smooth paper'. However, he said that the tactile sensation perceived could be due to the nature of the crayon. "*This is like smooth paper. Or maybe the crayon or the nature of crayon is like this. Even on different surface. I think, yes, it is like this.*"

Artist 22 made a similar remark as Artist 11. She preferred the tactile sensation of a '2B pencil' on 'smooth paper' but the pen-tool used could have a different grade based on the difference in terms of its smoothness from its real world counterpart: "*Feels sensitive. Yeah, again it will be that much pressure I get dark mark. And if I use a lighter pencil I would get a very light mark. So that feels more like a 2B and actually feels more like an 8B pencil. Softer.*" The comment on feedback in terms of the grade of the pencil was also supported by Artist 11. He hinted on the range of feedback using a 'graphite pencil' on 'smooth paper': "*I feel like it might be because of the visually and the brush stroke is different. I really feel like I'm using a graphite pencil. It's quite all right because of the range. I think not just the feedback but the visual responds because I feel the brush stroke here.*" He further explained by saying that artists use different drawing media to achieve different effects: "*Artists use different pencils because they want to achieve different brush strokes to kind of describe the object. Sometimes soft. If you want to use something really light then we can use thin but hard pencil. I think of different tools actually because of different reasons why they are used. So, yes.*"

Implications of Artists' Preferences Towards Pen Tool and Paper Type Combinations

The metaphor used in Interface 2 has influenced the artists' preference towards a particular pen tool and paper type selection. The study findings revealed that artists tend to prefer the combinations for which they perceive the haptic feedback as totally or partially like the real world counterpart. In this case, two different patterns of reasons for haptic feedback preference were observed. The first is realism of tactile sensation as suggested by the appearance of the metaphor used. For example, '2B pencil' on 'smooth paper' was perceived as similar to the actual drawing implements in the real world. The second is about realism of tactile sensation but the haptic experience may not represent what is suggested by the interface metaphor. For example, 'charcoal' on 'smooth paper' could feel like a pen on a whiteboard.

Realism of the haptic feedback may be a main factor for an artist to prefer a particular pen tool and paper type combination but this does not necessarily mean that the interface design is much preferred to the other interfaces. Artist 4 preferred 'roller-ball pen' on 'smooth paper' because the tactile sensation mimics reality: *"This feels like a roller-ball pen."* However, her reason for liking the inferred final preference of the interface as presented in Section 7.4 did not reflect realism as a factor in her decision. Her reason for choosing Interface 3 was that she could directly manipulate the three haptic dimensional cues.

On the other hand, preference towards a distinct haptic feedback from a particular combination of pen-tool and paper type could result in an artist preferring an interface as their inferred final preference. Artist 15 preferred the sensation of crayon on smooth paper. *"It's really like crayon. The thickness. Also the stickiness of the texture. It's quite good."* During the final debrief, Artist 15 stated she preferred Interface 2: *"Because I can feel more. I can associate with more items. It's virtual but I can feel that I'm drawing with crayon, which is quite interesting how my mind associate with the virtual drawing."*

However, the scattered distribution of pen tool and paper type combination preference indicates that the overall preference for Interface 2 presented in Section 7.6 is not dictated by preference towards a specific pen tool or paper type but the interface as a whole. Association of haptic feedback with that in the real world could influence the artists' preferences of a haptic sensation in a drawing interaction.

7.8.2 Preference for Haptic Cues in Interface 3

This sub-section presents the study findings pertaining to the combinations of haptic dimension cues preferred in terms of the tactile feedback felt. The intention is to make a deduction on which haptic cues are preferred in Interface 3. To facilitate this analysis the total number of artist preferences with respect to each cue combination that artists preferred to interact with is presented in Figure 7-5.

During the evaluation study, each artist could state as many preferences for haptic combinations as they wanted. This was plotted to see if the artists were considering the preference of Interface 3 as a whole, when compared with their preference with the other interfaces, or whether they were as a group being influenced in their preference by any particular haptic combinations. If the group of artists were giving even preferences across the interface, this provides some account for the interface being considered in their preferred choices across the sample of artists and not specific preferences within the interface.

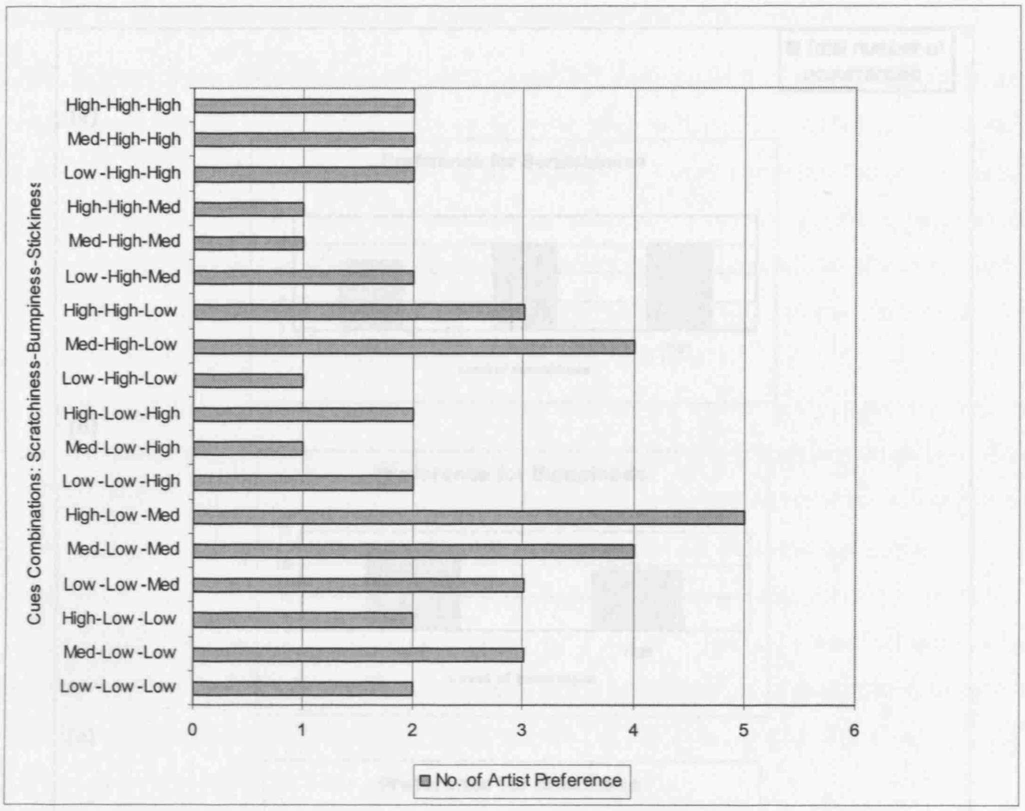


FIGURE 7-5: PREFERENCE FOR COMBINATIONS OF HAPTIC DIMENSION CUES

Figure 7-5 shows all the eighteen cue combinations used in the study with the total number of artist preferences for each combination in the evaluation study. Every combination is represented by the level of the dimension cues which are 'low', 'medium', and 'high' for scratchiness, and stickiness but only 'low', and 'high' for bumpiness. The combination of cues e.g. 'high-high-low' indicates the haptic feedback 'high' scratchiness, 'high' bumpiness, and 'low' stickiness.

The study findings reveal a wide spread of preferences with respect to the haptic dimension cue combinations for Interface 3. In this case it is essential to investigate the overall opinion of the artists in choosing the haptic dimension cues that they prefer to interact with. The fact that a total score of 24 (i.e. the total number of artists) was not achieved by any of the combinations indicates that no single particular cue combination dominates the artists' preference in Interface 3. This finding is parallel to the findings for the haptic cues preferences in Interface 2. However, the scores for the combinations preferred were lower than those in Figure 7-4. This may be because of less familiarity with the tactile sensations for the haptic feedback in Interface 3.

In order to examine the inter-dependency of the haptic dimension cues in Interface 3, a simple graphical representation derived from Figure 7-5 is prepared. This is presented in Figure 7-6.

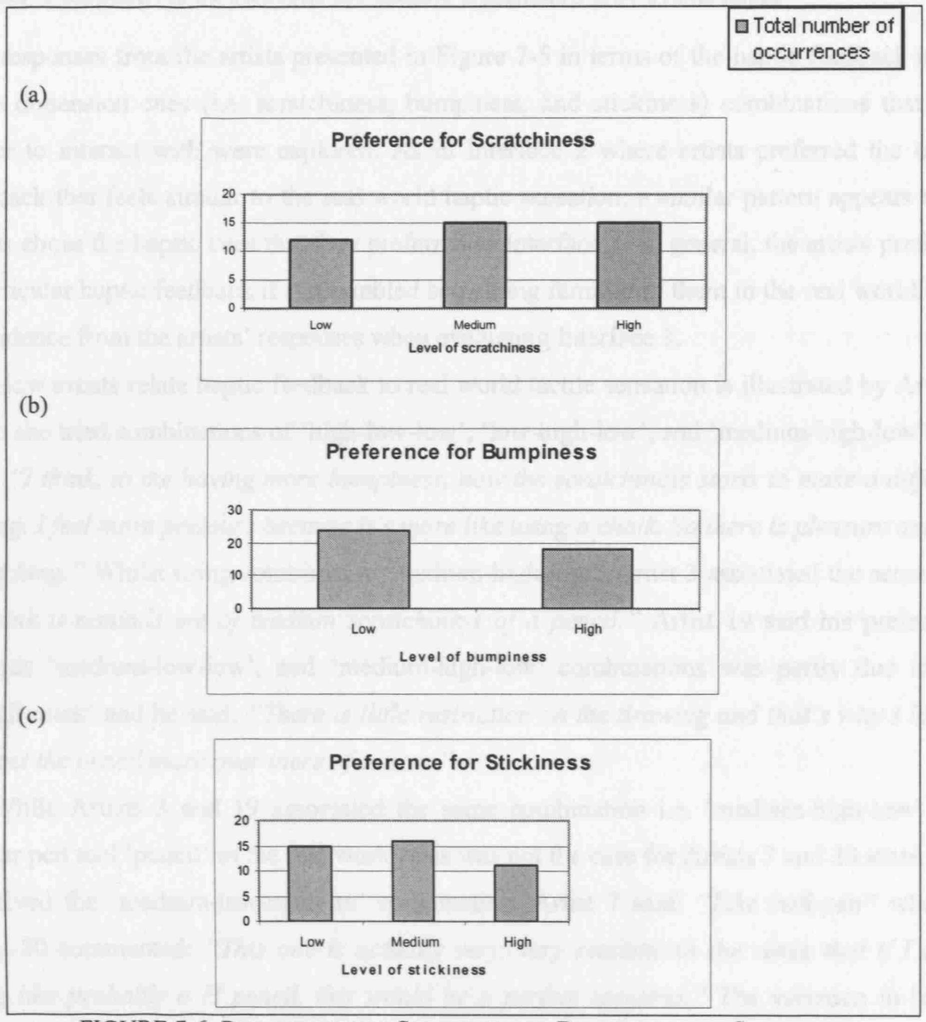


FIGURE 7-6: PREFERENCE FOR SCRATCHINESS, BUMPINESS, AND STICKINESS

Figure 7-6 consists of information on each individual haptic dimension cue for scratchiness, bumpiness, and stickiness. Each dimension cue is presented with the total number of occurrences in terms of artists' preference for a particular level of each dimension cue. These numbers were obtained from the information presented in Figure 7-5. For example, in Figure 7-6(a) the total number of artists for the 'low' level stickiness was obtained by adding all the combinations, which include 'low' stickiness in Figure 7-5.

The even distribution of the graphs in Figure 7-6 indicates there is no one particular level of the dimension cue that predominates in Interface 3. The scratchiness, bumpiness, and stickiness cues are inter-related to one another in order to be preferred by the artists. The graphs suggest that within the interface there does not seem to be any specific combinations that dominate the preferences for this interface. This implies that as a group the preference for Interface 3 is based on the preference for the interface.

Artists' Perspectives on Reasons for Haptic Dimension Cue Preferences

The responses from the artists presented in Figure 7-5 in terms of the haptic feedback of the three dimension cues (i.e. scratchiness, bumpiness, and stickiness) combinations that they prefer to interact with were explored. As in Interface 2 where artists preferred the tactile feedback that feels similar to the real world haptic sensation, a similar pattern appears when artists chose the haptic cues that they preferred in Interface 3. In general, the artists preferred a particular haptic feedback if it resembled something familiar to them in the real world. This is evidence from the artists' responses when evaluating Interface 3.

How artists relate haptic feedback to real world tactile sensation is illustrated by Artist 3 when she tried combinations of 'high-low-low', 'low-high-low', and 'medium-high-low'. She said: *"I think, to me having more bumpiness, now the scratchiness starts to make a different feeling. I feel more pressure because it's more like using a chalk. So there is pleasure and it's scratching."* Whilst using combination 'medium-high-low', Artist 3 associated the sensation: *"I think it reminds me of medium scratchiness of a pencil."* Artist 19 said his preference towards 'medium-low-low', and 'medium-high-low' combinations was partly due to the 'pencil mark' and he said: *"There is little restriction on the drawing and that's why I like it. You get the pencil mark over there of course."*

While Artists 3 and 19 associated the same combination i.e. 'medium-high-low' to a similar pen tool 'pencil' in the real world, this was not the case for Artists 7 and 20 when they perceived the 'medium-low-medium' combination. Artist 7 said: *"Like ball-pen"* whereas Artist 20 commented: *"This one is actually very, very realistic in the sense that if I draw using like probably a H pencil, this would be a perfect scenario."* The variation in haptic perception shown in the remarks made by Artists 7 and 20 indicates that artists can perceive a particular haptic feedback differently. This could be due to the haptic experience that they have encountered before.

Other examples show artists associated a particular haptic feedback when they recognised the feeling of the sensation perceived include Artist 13 on the 'low-low-high' combination: *"It's more like a crayon"*, Artist 2 on 'high-low-low': *"Scratchy feels like charcoal. Charcoal is scratchy. I kind of like this one surprisingly."*

The examples so far have shown an association of haptic feedback perceived with various pen-tool implements in the real world. However, for a particular haptic feedback combination to be preferred this may not be restricted to a selection of pen-tools and paper type. Artist 3 noted his preference for 'medium-high-medium': *"Definitely better because I can feel the shaking, exactly when I'm drawing on wood, for example."*

Implications of Artists' Preferences Towards Haptic Dimension Cues Combinations

A pattern was identified when observing how an artist chooses a particular haptic dimension cue combination with regards to a haptic feedback that she prefers. The analysis indicates that feedback that is perceived as similar to the real world haptic sensation tends to be preferred. This is regardless of whether the haptic feedback feels realistic to the actual drawing tools in the real world or just partially. This observation is parallel to the study findings revealed for the haptic cues preferred in Interface 2 in which realism is a main factor for deciding a preference. In the case of Interface 3, the artists tried to relate their new tactile experience with those that they have encountered in the real world.

In most cases, artists tend to choose a similar kind of haptic feedback that they prefer in both Interfaces 3 and 2. For example, Artist 2 preferred the 'high-low-low' combination of Interface 3, which she associated to the feel of a charcoal. Previously, in Interface 2 she chose the combination of 'charcoal' on 'rough paper' as one of her preferred choices in terms of the haptic feedback received. This parallel coincidence with the study findings in Interfaces 2 and 3 for Artist 2 could be due to her preference for a drawing implement in the real world. When asked the pen-tools that she used in the real world, she replied: *"In real life? I actually like charcoal."* Interface 2 was Artist 2's inferred final preference as highlighted in Table 7-2.

Similarly in Artist 22's responses she prefers using charcoal in the real world and such a preference was reflected in her choices in Interfaces 2 and 3. With reference to Interface 3, she said 'low-high-high' reminded her of charcoal. Unlike Artist 2 who preferred Interface 2 as her inferred final preference, Artist 22 chose Interface 3 as her preferred Interface.

A preference for a particular haptic feedback in the real world may not always necessarily be transferable to Interfaces 2 and 3. A different kind of haptic feedback could be chosen in Interface 2 and 3 and such choices may not be similar to what one prefers interacting with in the real world. Artist 6 preferred to use a softer grade of pencils in the real world: *"I always prefer softer pencils to harder pencils."* When choosing the pen-tools and paper type combinations preferred in Interface 2, among his choice of preference was 'graphite' on 'smooth paper'. This choice reflects his tactile preference in the real world. His preference in Interface 3 was the opposite as he chose the 'high-high-high' combination, which is the extreme case of the haptic dimension cues. Such difference could be justified by his reasons: *"A novel experience in mark making or visual representations I want it to be more extreme. Being different from reality. And it is still interesting to use something that is to mimic a surface and I can distinguish between the scratchiness and bumpiness in terms of how it is trying to replicate what it feels like if you are drawing in a reality. It is distinct."* In the case of Artist 6, the inferred final preference was Interface 3.

Artist 6 signifies a metaphor used in presenting the haptic information in Interface 3. The responses obtained from Artists 2, 6, and 22 have highlighted that artists' preferences vary when dealing with the haptic feedback. The even distribution of haptic cue combination preferences indicates that the overall preference for Interface 3 presented in Section 7.6 is not dictated by a preference towards a specific combination but the interface as a whole. A similar feature in terms of haptic sensation preferred in Interface 2 was observed in Interface 3 that is an association of haptic feedback with a sensation familiar in the real world is preferred in a drawing interaction.

7.9 Haptic Vocabularies in the Real World and Computer Environment

This section describes the study findings to compare the haptic vocabularies used when describing the tactile sensation during artists' drawing interactions using Interface 2 with those results in the earlier study presented in Chapter 3. The analysis involves examining whether the three dimension cues, i.e. bumpiness, stickiness, and scratchiness, could still be identified as a pattern for a drawing interaction, which has a real world object-based interface metaphor. The idea is to determine whether the tactile experience of drawing activities in the real world is transferable to a computer environment. This section is to address Objective 4 from Section 7.2.

7.9.1 Analysis of the Vocabularies Used in Interface 2

Using a similar technique for identifying vocabularies of haptic cues that artists used to describe the tactile sensation during a drawing interaction as described in Section 3.2.5, the transcribed data from the 24 artists who took part in the evaluation study were examined. This exercise involved recognising the terms used by each artist across all pen-tool and paper type combinations, and grouping any similar language under the same category. For example, the terms *"scratchy"* ('3H pencil' on 'smooth paper', Artist 8; 'Felt-tip pen' on 'smooth paper', Artist 22), *"more scratchy"* ('Ball-point pen' on 'rough paper', Artist 22), *"very scratchy"* ('Charcoal' on 'smooth paper', Artist 6), *"a bit too scratchy"* ('Charcoal' on 'rough paper', Artist 3), and *"sharp"* ('3H pencil' on 'rough paper', Artist 13) as expressed by the artists to descibe the pen-tools and paper type combinations were categorised as one group. Each group identified was given a name to signify the haptic features in it. In this example, the group was labelled "sharp/scratchy". A complete categorisation and labelling of group names for the haptic features in this exercise is presented in Appendix 7-8.

To maintain consistency in identification of the terms used, an orthogonal data analysis was performed in which the transcribed data from the 24 artists were transformed into 8 different sets based on the pen-tools used in the study. Similarly, based on the pen-tools and paper type combinations, the terms used by the artists to describe the tactile sensation were identified and grouped according to their similarity in the language used. No major inconsistencies were found when these terms and groupings were cross-examined.

It should be noted that the implementation of Interface 2 only supports active haptic explorations in order to feel the intended haptic feedback of the pen-tools on paper types. This constraint limits our comparison to the haptic features between the findings from this evaluation study and from those in the 'Friction' properties that correspond to the 'Push' actions of the 'Tool & Surface' type of interactions presented in Table 3-1.

7.9.2 Study Findings for the Haptic Vocabularies Used

The data analysis has resulted in a set of haptic features during the drawing interaction as presented in Table 7-4.

TABLE 7-4: COMPARISON OF HAPTIC VOCABULARIES

Haptic Features as extracted from Table 3-1		Haptic Features obtained from interaction with Interface 2	
Soft	Hard	Soft	Hard
Sticky	Dry	Sticky	Dry
Waxy	**Powdery**	Waxy	
Smooth	Glide	Smooth	Glide
Flows	**Silky**	Flows	
Velvety	**Creamy**	Velvety	
Stiff	Sharp/ scratchy	Stiff	Sharp/ scratchy
Bumpy/ rough		Bumpy/ rough	
		Rubbery	
		Slippery	
		FLAT	
		HARSH	

Table 7-4 presents the haptic features when active exploration was involved for both the study described in Chapter 3 and this evaluation. The first column presents an extraction of related information pertaining to the haptic features from Table 3-1 while the second consists of the corresponding features for Interface 2. All haptic features shown in each column are presented in no particular order.

In the first column, those haptic features which are highlighted in bold represent the elements that were not identified during the evaluation study with Interface 2. In the second column, the elements represented in italic are those that were identified in Table 3-1 but in the section that corresponds to the 'Hand & Tool' type of interaction, 'Hold' action, and 'Surface texture (tool)' properties. Those elements that are highlighted in bold and capitalised are new haptic terms in this analysis that were not identified in Table 3-1.

7.9.3 Implications for the Vocabularies Used

When comparing both sets of haptic features in Table 7-4, the fact that the majority of haptic elements appear in both columns indicates that artists tend to use a similar kind of vocabulary to describe their tactile experience in a computer drawing interaction to that in the real world situation. The tactile sensation obtained from the same pen-tool and drawing paper combination has also been consistently described or associated with a similar kind of expressions by most artists. In other words, each pen-tool and paper type combination has been agreed to have a similar type of haptic features.

The similar vocabularies found, and the consistency of the terminologies used across artists in determining the haptic sensation, have allowed an identification of the three haptic dimension cues, i.e. bumpiness, scratchiness, and stickiness, and their neutral point, smoothness, to be made from a computer-drawing environment. However, the experience in this environment tends to be slightly different from the real world mainly due to the nature of the drawing medium used for interactions. For example, 'powdery', 'silky', and 'creamy' are among the elements that are very rich in terms of the tactile sensation in the real world that may pose a challenge in simulating them in a computer environment. In general, these types of tactile sensations were perceived when dealing with the nature of the pen-tool materials used. On the other hand, the simulation of haptic cues involved in the study may have resulted in obtaining the tactile sensation that is slightly different from those in the real world. For example, 'rubbery' and 'slippery' were two haptic features identified in Table 5-1 when artists described the tactile sensation of the pen-tools as they hold and feel them in their hands. In the real world, such sensations were among the features of the pen-tools' physical haptic properties but have been identified by the artists during their interactions using a pen-tool and paper surface simulation. This indicates that, despite the fact that the artists found the simulated haptic feedback felt similar to the real world there are still some haptic elements that they perceived to be mechanical and unnatural.

The study findings that show the similarity of vocabularies used in both worlds signal that, to some extent, the haptic experience when drawing and sketching in the real world is transferable to a computer environment.

7.10 Discussion

The role of metaphor as a memory aid (Blackwell, 1998) has been applied in interface design. Reification of metaphor (Blackwell, 2006) can make the abstract haptic sensation from a drawing interaction concrete. During the evaluation, the artists utilised the visual metaphors presented on the interface to decide the tactile sensation that they preferred for a drawing interaction. The metaphor employed in the study influences the factors that affect user preference of tactile experience for a drawing application. Such factors are based on artists' familiarity with the real world interaction and user control, and a balance between a new experience and familiarity of the haptic sensation. The relevance of metaphor in presenting haptic information has led to a discussion of whether metaphor enhances or hinders user haptic experience in a drawing interaction. What suggestions would be appropriate to address the issues if metaphor hinders user experience?

7.10.1 Metaphor Used Enhances User Experience

The evaluation study provides evidence that a metaphor enhances user haptic experience when the underlying haptic parameters match the sensation artists had expected. In the case of Interface 1, it fails to convince artists of its "reality" in terms of the tactile sensation. Almost all artists in the evaluation study noticed this situation. This condition could be explained by using Heidegger's concept of breakdown discussed in Section 2.3.2. The absence of haptic feedback that corresponds to the combination of pen-tool and paper type metaphors signals that something 'not quite right' is happening in the interaction. In this case, the metaphor has helped the artists to differentiate the haptic feedback from Interface 1 with what they have experienced and understood in the real world. This gives a reason as to why either Interface 2 whose haptic metaphor linked to suggested pen tool or Interface 3 whose haptic metaphor is consistent with user control based on degree of bumpiness, scratchiness and stickiness is preferable to Interface 1 where there is no designed haptic metaphor. At this stage, the study finding has answered research question 4 stated in Section 1.2, i.e. *in a drawing application, do users prefer manipulating a fixed haptic interface or its "variable haptic" counterpart?* Based on the 24 artists, Interfaces 2 and 3 that represent the variable haptic interfaces are much preferred to Interface 1, the fixed haptic counterpart.

The study findings that present the effect of metaphor on user experience presented in Section 7.6 has also answered research question 5 from Section 1.2, i.e. *If a variable haptic design is preferred, do users prefer to interact with haptic information represented in a system using an interface metaphor design that involves a:*

(i) real world object-based in which underlying haptic sensation feels similar to its real world counterpart, or

(ii) *textual description of the underlying feature that corresponds to an intuitive haptic sensation?*

In this case the positive haptic experiences presented have explained artists' reasons for preferring each of the variable haptic interfaces, i.e. Interfaces 2 and 3.

The metaphor used for Interface 2 has helped the artists to build their own expectation of the tactile sensation to be felt based on their previous experience. This is in line with Wells and Fuerst's (2000) assertion that metaphor must be suitable and familiar to users to take advantage of previous domain knowledge and experience. The artists expected the underlying haptic parameters in Interface 2 to reflect reality. When such a prediction is met, artists tend to prefer the interface and also rated it as being helpful to them. Where the metaphor was not perceived in line with the haptic description, not all pen tools and paper type combinations were preferred by the artists.

The familiarity of the metaphor used for Interface 2 is a possible reason for this interface to have scored better in the 'helpful' criterion than Interface 3. This is consistent with Wells and Fuerst (2000) and Vaananen and Schmidt (1994), who argue that concrete real-world-based object metaphors should be considered prominently because of their familiarity and attractiveness to most types of users, especially for first time and casual users of a system. This situation is parallel to the case of the artists who were first time users of the PHANToM and the haptic drawing system. This result also indicates that diagrams as used by Blackwell (1998), using pictures and text describing the images, are adequate as a visual metaphor to represent haptic information for a drawing application. This is supported by Gaver (1995) (Section 4.2.1) indicating that mixed metaphors, i.e. names and graphics, allow two models to both add and constrain one another since names are capable of strengthening the functionality expressed graphically.

To date, little attention has been focused on user haptic experience in the design requirements of art haptic applications, as most work concentrates on the technical aspects of the interactions. This raises a concern that users may reject a product if it does not have the functionalities that they require. As presented in Section 2.3.2, users may not want to use a drawing system if it does not provide additional features to them. So is it necessary to mimic reality in terms of haptic sensation when developing a drawing application?

The study findings of the preference exercise revealed that in the case of Interface 3, the metaphor to represent the haptic sensation is acceptable to the artists. Artist 19 indicated his dislike of using a computer drawing application. He said: *"I prefer to use the real pencils!"* However, the fact that he preferred Interface 3 as his inferred final preference is an indication that the additional feature that is the intuitive haptic sensation may have persuaded him to like the interface. This correlates with Scali et al (2002) that artists only use computers if they provide additional functionalities that could support the tasks the artists are doing. This finding also implies that not only haptic feedback should be included in a design but a consideration of the way haptic information is presented to the users.

The metaphor for Interface 3 was designed by exploiting user experience in expressing haptic sensation when using drawing tools in the real world. The 'everydayness' concept helps in artists' learning and understanding the interface metaphor used in the prototype. Artist 9, as described in Section 7.4.3, noted the interface metaphor of Interface 3 is easy to learn. Her response correlates with Wells and Fuerst's (2000) work described in Section 4.2.1 which stated that metaphor must be suitable and familiar to the users, and their design should take advantage of users' previous domain knowledge and experience. Artist 9's remark is an example that indicates to some extent that the metaphor used in Interface 3, which does not involve a real world object-based metaphor, is also familiar to the users. Such familiarity, which corresponds to the way people describe a tactile sensation from an object they touch as discussed in Section 2.2.2, seems to support such a familiarity feature in a haptic interface design.

Haptic exploration (described in Section 2.2.1), which occurs during a drawing interaction, enables the artists to feel the changes of the surface texture profiles implemented in the system. Their ability to feel these textures makes the drawing interaction more controllable and also creates a feeling of "making or doing something". The haptic sensation felt could be a reason both Interfaces 2 and 3 were rated equally in terms of being 'enjoyable' in Section 7.4.5. Such enjoyment for Interface 2 has been explicitly expressed by the artists from their subjective haptic experience presented in Section 7.4.3. Similarly, artists felt that the ability to directly manipulate and control the haptic parameters on Interface 3 is fun. Some artists thought that the visual metaphor used for the interface does not create any expectations for the tactile sensations to be felt, hence making the experimentation of the haptic feedback to generate different sensations more interesting. This situation may have led to the artists enjoying the interaction using Interface 3.

The fact that Interface 3 allows experimentation on the haptic sensation has resulted in some artists preferring the extreme sensations such as the 'high' scratchiness, 'high' bumpiness, and 'high' stickiness because the sensation has been associated to a feel of being freer and more creative. This could be a reason this interface was rated better than Interface 2 with respect to the "supportive of creativity" criterion. However, from the artists' subjective haptic experience presented in Section 7.4.3, it could be argued that this criterion could also be applicable to Interface 2 because the haptic feedback provided has been described as able to engage artists with their expressive feeling.

7.10.2 Metaphor Used Hinders User Experience

The effect of metaphor in presenting abstract information such as the haptic sensation for a drawing interaction has been presented in Section 7.4.3. The study findings that explained the negative user haptic experiences show that at times the visual metaphor used to represent the haptic information could hinder user experience. One of the factors for such experience is when the visual metaphor used is perceived as less familiar to the artists. This situation comes across in a few cases in Interface 3 when artists compared the visual metaphor of the interface with those in Interfaces 1 and 2. Despite some artists saying that Interface 3 could be easily learnt, some noted that it is more complex than Interface 2. Interface 3 requires artists to construct their own media from the combination of haptic cues. Those who had reservations with Interface 3 did not particularly like this feature as they might not be able to relate the haptic sensation they know with a specific tool. When they found the haptic sensation that they preferred to use, it was still difficult to remember the combination as compared to the pen tool and paper type metaphor used in Interface 2.

The metaphor used for Interfaces 1 and 2 has built up an expectation of the haptic sensation to be perceived as well as the visual lines when using the pen tools. The expectations on the visual cues are not the focus of the research. A tendency to relate pen tool with the visual effect correlates with Sanderson's (1658) statement presented in Section 2.4.1, which urges artists to use their entire visual sense when drawing.

When experiencing the haptic feedback suggested by the visual metaphor, the haptic sensation perceived in Interface 1 has resulted in a perception that it is easier to make a mark on the interface as compared to Interface 2, despite the fact that the visual effect for both Interfaces 1 and 2 has been implemented in the same manner. In the case of Interface 1, the visual effect becomes apparent whereas it does not in Interface 2. This relates to Lederman and Hamilton (2002) (see Section 2.2.1) on the role of haptics when a visual cue is present. When interacting with Interface 1, that feels smooth throughout the interaction as perceived by most artists, visual perception dominates; hence, the perception of macrogeometry (i.e. the shape of the line drawn) is more obvious.

When experiencing the haptic feedback for Interface 2, the variation of sensation with respect to the suggested metaphor has made the perception of microgeometry (i.e. texture) become more dominant than the perception of macrogeometry. As a result, the artist tends to focus on a specific haptic feature and expect a differentiation of line effects when using different pen-tools. To some extent the visual effects received may have also influenced artists' judgement in assessing the haptic feedback of the object-based metaphor interfaces. They tend to associate the mark produced with the pressure that they applied on the drawing surface and the haptic feedback expected from the interaction. The fact that the prototype does not correspond to realistic interaction behaviour disappoints some artists when using Interface 2 that is designed to mimic real world sensation.

7.10.3 Addressing the Limitation

In Section 3.5.2, creative artwork such as DAB using a haptic rendering technique that takes into consideration the pressure and speed of a painting interaction was discussed. Replicating this technique to simulate haptic feedback in the prototype may result in addressing the haptic sensation with respect to the pressure applied during an interaction. In theory, having better haptic rendering will better replicate reality. This could probably address responses from artists who felt that the tactile sensation only partially mimics reality. This could involve a better implementation of the haptic prototype in which the differentiation of the haptic feedback received between the 'press' and 'push' actions as indicated in the preliminary taxonomy of haptic features for the drawing domain presented in Figure 5.1 could be addressed. However, how much reality is needed to satisfy user requirements?

Artist 20 provides an insight into answering this issue of satisfying a haptic user requirement. When evaluating 'charcoal' on 'smooth paper' in Interface 2 he commented: *"I guess no matter how you sort of try to compensate this in programming the machine you know there is still no way that you actually make a charcoal pencil"* In relation to this Bordegoni et al (2001) (see Section 2.2.2) noted our ability to distinguish point-like events from force feedback generated by a PHANToM and to mentally integrate in time the continuity of a sequential signal, enabling us to feel the haptic sensation when touching the surface. If we are able to exploit human weaknesses in perceiving haptic feedback, we may still be able to present haptic information that meets users' requirements. As discussed in Section 3.2, Hayward et al (2004) noted that users are able to adapt to the imperfection of a rendering technique to recognise a particular haptic sensation. Hayward's argument has been seen in some of the artists' responses. In this case, users experience could be a way to decide to what extent reality is needed to mimic the haptic sensation.

7.10.4 Some Reflections on Generalising from the Study Findings

The haptic drawing prototype evaluated in the study was represented using three interfaces. Interfaces 1 and 2 shared the same visual abstraction of pen tool and paper type features displayed on the screen, while Interface 3 has the textual description of haptic feedback with a specific level of sensation, namely 'low', 'medium', and 'high'. Improvements made on these interfaces could, for example, include real images of pen tools and paper type surfaces as used in the study described in Chapter 3 for Interfaces 1 and 2, a slider version to represent the degree of haptic sensation for Interfaces 3, and a better haptic rendering as described in

Section 7.10.3 for all three interfaces. Such improvements to the appearance of the interfaces may affect user experience whilst interacting with the interfaces. This prediction is revealed from one particular artist described in Section 7.6.1 who enjoyed the tactile sensation of pen-tools on rough paper in Interface 1. The visual appearance of the rough paper on the computer screen may have influenced this artist's perception of haptic feedback. This situation indicates that a particular set of user preferences could be obtained based on a specific set of interfaces. In this research project, minimum feasible changes between the interfaces were made in order to focus on the matter of concern i.e. the haptic metaphor. This is seen in the dependency of the development of haptic sensations in Interface 3 that was based on Interface 2. The focus on haptic metaphor was intended to obtain study findings that reflect the artists' responses towards the haptic features rather than other elements of the different interfaces. However, since many aspects of context can influence subjective data, it is impossible to be certain how the study findings generalise. By minimising the non haptic changes between the interfaces, it is aimed to maximise the chances of the findings generalising.

7.11 Chapter Summary

This chapter evaluated three different haptic interface designs for a drawing prototype. The designs involved are: (i) a pen tool and paper type metaphor interface, that has no designed haptic feedback (ii) another pen tool and paper type metaphor interface that has underlying haptic parameters that mimic reality, and (iii) an abstract haptic parameter interface that reflects an intuitive underlying haptic system.

The first study objective which is to test the effect of metaphor on users' haptic expectation was addressed and answered in Section 7.5. The evaluation study revealed that artists expected the haptic sensation for a drawing interaction based on the visual metaphor suggested to feel similar to the corresponding sensation they had experienced in the real world. This was shown in the cases of Interfaces 1 and 2 that have pen tool and paper type visual metaphor. No particular feeling of haptic sensation was expected from Interface 3 that had an abstract haptic parameter metaphor.

The second study objective which is to test the effect of haptic metaphors on user experience was addressed and answered in Section 7.6. Based on artists' haptic experience, Interface 1 did not meet their expectation as the tactile sensation did not reflect what was suggested by the visual metaphor. On the other hand, Interface 2 was reported as realistic in terms of its haptic metaphor sensations. This has resulted in an enjoyable haptic interaction. From the artists' pespective, the familiarity of the visual metaphor used helps them to recognise the intended haptic sensation. This could be a possible reason Interface 2 was rated better than the other interfaces on the 'helpful' criterion. Some of the artists have expressed their concerns about the difficulties in drawing using the interface as the haptic sensation and line mark did not correspond to the pressure they applied on the drawing surface. This was due to the limitation of the prototype and also beyond the scope of this research. In the case of Interface 3, the artists found the haptic experience very interesting, as they were able to directly control and manipulate, and experiment with the haptic feedback within the parameters specified. These positive user experiences could be a possible reason Interface 3, scored better than the other interfaces for 'supportive of creativity' criterion. Both Interfaces 2 and 3 scored equally for the 'enjoyable' criterion. However, some artists thought the metaphor to represent haptic feedback in Interface 3 was more complex than that for Interface 2. The artists' haptic experience when interacting with these three interfaces answered the second objective of the evaluation study. The fact that a statistical analysis is not involved in this evaluation study limits generalisation on association between artists' preferred interface with respect to the generic user experience goal criteria and the preferred inferred interface.

The third study objective which is to investigate the user experience on the tactile sensation preferred was addressed and answered in Section 7.8. In the investigation, the distribution of artists' preference for each pen tool and paper type combination in Interface 2, and haptic cue combination in Interface 3 was examined. A scattered distribution of artists' preference obtained for Interface 2 indicates that no particular pen tool and paper type combination dominated the artists' preferences. In general, artists preferred haptic cues in Interface 2 when the tactile feedback felt familiar to those that they could associate with their haptic experience in the real world regardless of what was suggested by the visual metaphor. Similarly, the even distribution of artists' preference for Interface 3 means no one particular haptic cue combination is preferred. Artists preferred those haptic feedbacks that they could either associate with the real world or were completely different from reality. The findings from this investigation highlight the features of haptic sensation that artists preferred in a drawing interaction.

The fourth study objective which is to examine the quality of haptic sensation for the interface that has pen tool and paper type metaphor whose underlying haptic parameter mimics reality was addressed and answered in Section 7.9. The haptic sensation perceived when interacting with Interface 2 was examined to see how different it is from using the actual drawing tools in the real world. In this case the vocabularies used to describe the tactile sensation interacting with Interface 2 were compared with those study findings presented in Chapter 3. The study findings showed that similar kinds of vocabularies to describe the haptic sensation in the real world were used when expressing the haptic feedback in Interface 2. The metaphor employed on the interface has influenced the artists in describing the haptic sensation felt. To some certain extent the haptic experience when interacting with Interface 2 is similar to that in the real world.

This evaluation study demonstrates the haptic sensation metaphor affect the artists' experience interacting with the drawing prototype. This process and the findings of investigating artists' preferences provide a contribution towards seeking for such haptic experiences. The summary and the contributions from this research are presented in Chapter 8.

Chapter 8 Conclusion and Further Work

8.1 Introduction

The aim of this chapter is to conclude the findings of this research project by relating them to the research questions specified in Chapter 1. The intention is to determine whether the objectives and contributions of this thesis have been achieved. This chapter also presents related future research directions as follow-up research from this thesis.

The chapter summarises the study findings obtained from the three practical works presented in Chapters 3, 6, and 7. The summary consists of the tasks that have been performed and the limitations of the studies. The chapter progresses by re-emphasising the research questions to be addressed and the contributions to be offered. A summary of suggestions is presented to indicate the completion of the research within the specified focus and goals. The chapter ends with a section that highlights future work suggested from this research. This is also aimed towards addressing some of the limitations of the studies presented in this thesis.

8.2 Taxonomy of Haptic & Visual Cues (Chapter 3)

The study in Chapter 3 focused on the haptic sensations that artists recognise in a drawing interaction. The main intention of the study was to compile a structured vocabulary of users' experience when using the drawing tools.

The study findings have resulted in a preliminary taxonomy that consists of haptic cues for a drawing domain. The taxonomy is unique in the sense that it incorporates the action involved during a drawing interaction i.e. 'Hand and Tool', 'Tool and Paper', and 'Hand and Paper'. In this research project, the focus was upon 'Tool and Paper'. The taxonomy also highlighted the visual properties and features involved. Others may use them for further investigations although these aspects were not explored in this thesis. This thesis is not claiming that the taxonomy proposed is complete, as the investigation has used a limited number of pen-like tools and paper types. This has posed a limitation to this study. However, it is adequate to provide a preliminary taxonomy, developed from this context, for the drawing domain at this stage, and its formulation is replicable in other contexts.

In terms of an appropriate choice for a haptic drawing interface, the features associated with the 'Tool and Surface' have been suggested as suitable for such integration. The 'scratchiness', 'stickiness' and 'bumpiness' haptic dimension cues were formulated based on the study findings. A closed card sorting activity was performed to validate these cues. The intention to have a wider and more generic set of dimensions was to facilitate the development of a drawing application whilst ensuring all haptic cues were considered.

8.3 Simulating the Haptic Cues (Chapter 6)

The practical work presented in Chapter 6 involved an implementation of a haptic drawing prototype. The three haptic dimension cues, i.e. scratchiness, stickiness and bumpiness obtained in the study described in Chapter 3, were incorporated into the interface designs. The intention was to address the issue of providing options to users so that they could work with the force feedback to suit their own needs as argued by Yu and Brewster (2003). The practical work presented in Chapter 6 demonstrated how a simulation of the haptic effect could be done.

The HapticDraw prototype was developed primarily to cater for two design ideas in terms of interface options in which the haptic feedback for a drawing interaction could be embedded. The design options involved were: (i) Option A - a real world object-based interface metaphor whose underlying haptic parameters mimic reality (i.e. Interface2), (ii) Option B - a textual description of haptic feedback that reflect a creative and intuitive underlying haptic system (i.e. Interface 3). The haptic effect implemented was basically using a simple rendering technique that manipulates the surface texture of a drawing surface and the haptic parameters from the PHANToM. Users are able to perceive the haptic feedback when an active exploration is performed on the drawing surface. There is a drawback in the prototype whereby it does not behave naturally with respect to drawing behaviour in the real world. The speed and pressure applied during a drawing interaction could not be supported by the system. A limitation of the prototype was that the visual cues with respect to the interaction of the pen-tools and paper types were not accurate as those in the real world drawing situation.

The design of interfaces in the HapticDraw prototype was primarily influenced by the concept of interface metaphor whose main role is to aid memory. Three versions of haptic interfaces that used the design concepts in Options A and B were implemented in order to prepare for the evaluation study in Chapter 7. Interface 1 is a fixed haptic interface, which adopts only the concept of visual appearance of the interface design described in Option A. Interface 2 is a variable haptic interface that follows fully the design concept of Option A. Interface 3 is another variable haptic interface that follows the design concept of Option B.

The 'variable haptic' terminology was used to reflect the changes in terms of the haptic feedback that correspond to the features (widgets) selected on the interface. The 'fixed haptic' interface (Interface 1) in which the same haptic effect was presented to the users throughout their drawing interactions was implemented in order to enable a comparison between the variable and fixed haptic interfaces to be made.

8.4 Evaluating the Haptic Interface Design (Chapter 7)

The evaluation study conducted in Chapter 7 was to seek users' preferences towards the haptic interface designs. It is necessary to conduct an investigation based on users' preference and to support their experience goals in order for a haptic drawing application to be accepted. This correlates with gaining users' acceptance through a careful interface design, which manipulates users' experience and perceptions.

The analysis of the study findings targeted various ranges of user preference levels; ranging from a high level view about the haptic cues to fine detail of the vocabularies used when describing such cues in a specific interface design. The question of whether haptic cues matter in a drawing interaction was examined. Such findings have led to an analysis of the types of haptic interface design preferred and the haptic cues favoured. The vocabularies used to describe the tactile sensation from the interface design that mimics reality was examined.

From the study findings with a group of 24 artists, Interface 1 which represents the fixed haptic interface design, was not in favour by the artists when compared to Interfaces 2 and 3, the variable haptic interfaces; this indicates that haptic cues are valuable in a drawing interaction. Interface 1, which has the same pen-tool and paper type appearance of the interface metaphor and visual drawing marks as Interface 2, did not in general bias artists' decision in assessing the tactile sensation felt. The ability of the artists to distinguish the haptic feedback in Interfaces 1 and 2 has generally been influenced by their mental model built after perceiving the interface metaphor used and associating the knowledge learnt about the metaphor with what they have already understood in the real world.

The study findings revealed that the artists almost equally prefer the haptic interface design that mimics reality and the one that is intuitive. Both interfaces were shown as two possible interface design candidates for a haptic drawing application. Interface 2 shares a common feature with the majority of art haptic applications presented in Section 4.4.2 whereas Interface 3 is a unique haptic interface design with regards to using concept of metaphor to represent haptic information in a drawing environment. The acceptance of artists towards Interface 3 has also signalled the appropriateness of the approach taken in formulating the three haptic dimension cues (Chapter 3) and the implementation of the interface design (Chapter 6).

The responses from the artists revealed that Interface 2 was preferred mainly for the interface metaphor being familiar and similar to the haptic sensation to those in the real world. Interface 3 was preferred for its interesting haptic feedback, and allowing interaction with the feedback. This interface was also in favour because it allows users to manipulate the haptic dimension cues provided on the computer screen in order to *create one's own media*. As both interfaces fall under the category of variable haptic interface design, they were preferred by the artists for having the feel of textures that correspond to the suggested metaphor. The haptic textures enable one to control the drawing as there is *a good balance* of feedback for an interaction. Also, the haptic feedback in both interfaces were said to be *fun* to interact with.

The results from ranking the three haptic interfaces based on a set of user experience goal criteria indicated that in all cases the variable haptic interfaces were ranked better as compared to their fixed counterpart. Interface 2 scored better than the other interfaces for being 'satisfying', 'helpful', 'rewarding', and 'aesthetically pleasing' while Interface 3 scored better on aspects that were 'supportive of creativity', 'fun', 'emotionally fulfilling', 'entertaining', and 'motivating'. Both interfaces were ranked equally in the 'enjoyable' criterion. The artists' individual ranking for these criteria have been checked against their final preference of the three interfaces to check for consistency in their judgement. Almost all artists were consistent in their decision-making. Since no statistical analysis was performed, no further claim could be made on the association between the preferred interfaces and the user experience goal criteria.

The analysis of the study findings indicate that there is no single combination of either pen tool and paper type in Interface 2 or haptic dimension cues that dominate the users' preferences in Interface 3. The concept of metaphor and the underlying haptic feedack associated to it has convinced the artists to prefer the interfaces. This was reflected in their haptic experiences reported in the study findings. In the case of Interface 2, realism of the tactile sensation is still a main influencing factor for the artists to prefer a particular pen tool and paper type combination. Similarly, in the case of Interface 3 the most preferred haptic dimension cues combinations are mainly those for which artists felt that the feedback was able to broadly replicate their haptic experience in the real world. Such experience may not necessarily come from a drawing implement, as employed in the real world object-based interface metaphor design version (e.g. Interface 2).

The study findings revealed that the vocabularies used to describe the haptic feedback during a drawing interaction using Interface 2 were similar to those in the real world. Putting the haptic effect into a specific context and providing a familiar interface metaphor as in Interface 2 may assist the users in describing the feedback perceived. Such familiarity of the haptic feedback is also indicated when the artists chose Interface 2 as more helpful than Interface 3 from rating the user experience goal criteria.

Comparing the set of haptic vocabularies used in this study with the one presented in Chapter 3, it could be said that to some extent the experience in describing the tactile feedback in the computer-drawing environment is transferable from those in the real world. Caution should be made here especially since some artists claimed that the haptic sensation feels unnatural and mechanical. No further claim could be deduced on the haptic experience transfer from this comparison study as it was beyond the scope of the research. It should be stressed that this comparison was not designed to compare the relative tactile experience of using the computer-drawing interface and the real world drawing interaction. Rather, the vocabularies used to describe the haptic sensation were more of interest.

In the evaluation study, the artists' final preference of a particular interface was inferred based on the comparisons made between two interfaces rather than making the artists rank the three interfaces with respect to the tactile feedback they prefer. This posed a limitation to the study in which a conclusion cannot be drawn as to whether it will always be the case that a fixed haptic interface scores the lowest in the preference ranking. It should be noted that the users' preference in this study was based on their experience within a short period of time. Perhaps, over time users may change their preferences due to their familiarity with the interfaces. However, this is beyond the scope of the thesis.

8.5 Key Questions Addressed in the Research

Chapter 1 introduced five central research questions concerning haptic interface designs for a drawing application:

1. *What are the haptic features involved in a drawing domain?*

2. *What are the haptic features suitable for a drawing application?*

3. *How do we integrate the haptic features identified in a design interface?*

4. *In a drawing application, do users prefer manipulating a "fixed haptic" interface or its " variable haptic" counterparts?*

5. *If a variable haptic design is preferred, do users prefer to interact with haptic information represented in the system using an interface metaphor that involves:*

   (i) a real world object-based whose underlying haptic sensation feels similar to its real world counterpart, or

   (ii) a textual description of the underlying feature that corresponds to an intuitive haptic sensation?

The first question addresses the users' haptic experience in a drawing and sketching environment. The question that follows immediately from this is what are the haptic elements suitable for a computer drawing application? These questions were addressed in Chapter 3. Using these results, the third question addressed in Chapter 6 focuses on the integration of haptic information into two types of interface designs. The fourth question was addressed in Chapter 7 through an evaluation study on users' preference interacting with either a fixed or variable haptic interface design. This led to addressing the fifth question whereby an exploration of the data from the evaluation study to find out users' preference of these two haptic interface designs was conducted.

8.5.1 Main Contributions

Research into haptic drawing applications is arguably still in its infancy, and as the haptic interfaces continue to mature there will be numerous improvements in presenting the haptic information. In terms of assessing users' haptic experiences in a drawing environment, views on the type of haptic interface designs that users prefer to interact with are continually developing. At present, however, there is scope for exploring the user haptic experience with regard to transferring real world tactile sensation of drawing tools into haptic interfaces.

The substantive contributions consist of empirical findings concerning the haptic cues suitable for a drawing domain, and the underlying ideas towards the development of the two types of haptic interface designs for a drawing application using the concept of metaphor. There is a contribution into the different roles of metaphor and the user experience criteria on which these alternatives are assessed. A preference towards interfaces with represented haptic sensations, as contrasted with an interface without designed haptics is proposed within this context.

A methodological contribution concerns a proposed research approach to studying users' subjective haptic experience when using drawing tools in the real world, and an evaluation study that investigated users' preferences of haptic interface designs in a drawing application.

Methodological Contributions

The literature review presented in Chapter 2 discussed user haptic experience and perception in perceiving haptic sensation in the real world. This thesis used the way people described the things they touch to elicit the tactile sensation in a drawing interaction. One of the methodological contributions of this thesis is the approach taken to address the first research question in finding the haptic features for a drawing domain. This approach is based upon an exploratory investigation on users' drawing experience in the real world (Chapter 3). The refinement of the haptic features resulted in three haptic dimension cues suitable for a computer drawing application. This addressed the second research question.

The thesis used the concept of reification of metaphor to make haptic information concrete on an interface, thus resulting in the development of a "fixed haptic" interface and two types of "variable haptic" interfaces. The evaluation study (Chapter 7) compared the interfaces, both qualitatively and in terms of ranked preferences. Simple preferences were compared against the results of assessing each interface against a set of user experience criteria. The approach of the evaluation study represents a contribution within the context of the development of a drawing application, from artists' subjective experience.

Substantive Contributions

A substantive contribution addresses the first research question concerning the haptic features involved in a drawing domain. This has been presented in the form of a preliminary taxonomy of haptic features that was formulated based on users' experience interacting in the real world environment with their tactual perception during such interactions (Chapter 3). From this taxonomy, the three haptic dimension cues 'scratchiness', 'bumpiness', and 'stickiness' have been extracted and validated for their suitability for a haptic drawing application. This addresses the second research question in the thesis.

The third question concerned the way integration of haptic information identified from research findings in the second question could be represented in a drawing interface. The underlying ideas in obtaining the two types of haptic interface designs constitute an important contribution. The literature review presented in Chapter 5 that emphasises the role and reification of metaphor motivates these ideas. The designs were derived from the two roles of metaphor i.e. representing 'similar', and 'dissimilar' abstract concepts transferable to an interface. The two designs are: (i) an interface which adopts a real world object-based metaphor whose underlying parameter mimics reality (ii) another interface whose metaphor involves textual descriptions of haptic feedback that reflect a creative and intuitive underlying haptic system. In order to test the effect of metaphor on users' haptic experience and perception another interface in the form of design (i) but with fixed haptic feedback was introduced. All these interfaces were implemented in Chapter 6.

The fourth question concerned the users' preference in manipulating the fixed and variable haptic interfaces. The research findings in terms of users' subjective experience assessing the haptic sensation of these interfaces provide a contribution. The findings from the preference exercise indicate that the effect of haptic metaphor on user experience resulted in variable haptic interfaces being preferred as compared to their fixed counterpart.

The study findings led to the fifth research question on the users' preference between the two variable haptic interfaces. The design interface which mimics reality was preferred mainly for familiarity with the metaphor, and the sensation being enjoyable. The design interface that had a user created haptic sensation was preferred for its interesting haptic sensation and allowing the user direct manipulation and control of the haptic parameters.

In a further evaluation on user preference of haptic sensation, the findings indicate that for both design interfaces, users prefer to interact with haptic feedback that they could associate with the sensations they had experienced in the real world. These sensations may not necessarily be from an interaction using an actual drawing tool. In assessing the quality of haptic feedback in the design interface that mimics reality, users tend to use similar vocabularies in the real world drawing interaction when expressing the haptic feedback in the interface. The fact that the role played by metaphor had an effect on user haptic experience suggests its importance when transferring real world haptic sensations of drawing tools into haptic interfaces.

8.6 Directions for Further Work

The research focused primarily on users' subjective haptic experience of drawing and sketching interactions, and haptic design representations to support these experiences. Users' subjective perceptions are particularly relevant to the potential acceptance of haptic systems such as in a drawing application whose benefit in terms of the haptic feedback may not be very obvious.

Based upon the study findings in Chapter 7, respectively, one main recommendation for follow up from this research project is to investigate the relationship between the visual and haptic effects on a drawing application. These two elements are important since both modalities play a big role in a drawing domain. The fact that haptic was the focus of this research project has made the visual features secondary to the work. To address this matter, the visual effect as suggested in the preliminary taxonomy of visual features in a drawing domain presented in Chapter 3 needs to be properly implemented in the system. For example, in future work, the visual effects of the lines drawn need to correspond to those of the real world drawing tools. This could be in terms of the size and colour effect of the drawing lines produced with respect to a particular pen-tool and paper type combination. Improvement on the appearance of the interface such as the actual image of the pen tools and paper surfaces, and a slider to represent haptic sensation as suggested in Section 7.10.4 could also be incorporated into the prototype. This could enhance user experience when interacting with the haptic drawing application.

In researching the relationship between the visual and haptic effects, imitating the real world drawing behaviour should be considered as well. The visual features in the object based interfaces need to correspond to the amount of pressure applied, and speed and gesture made during an interaction. The haptic and visual information need to synchronise as suggested in the preliminary taxonomy of haptic and drawing features presented in this thesis. This could include a proper implementation of haptic and visual cues with respect to the 'press' and 'push' actions of the taxonomy. In this case, the haptic feedback received does not solely rely on a haptic exploration; rather, it depends on the users' drawing interaction.

To carry out research in enhancing the visual effect and transferring the real world drawing behaviour into a haptic drawing system requires a different haptic rendering technique to be used. This could be another important recommendation for future work. In this case, real-time physically based simulation algorithms for deformable tools and surfaces need to be designed and implemented. This suggestion corresponds to the physical modelling for an interface (Burdea, 2000) discussed in Chapter 2. Calculating and sending haptic information based on an instant of collision detection between the pen-tool and paper surface, and allowing the material of the pen-tool to deform, may create a more realistic drawing environment. Such a scenario could be established if a better haptic rendering technique such as that described in the implementation of the DAB system is to be adopted. Not only could the suggested technique enhance real world object-based interfaces but also the textual description interface may benefit from a more advanced rendering method. In the case of the latter, users could find the drawing interaction more realistic if the visual lines produced synchronise well with the tactile sensation perceived as a result of the drawing interaction. This should include a mechanism to detect a collision between the pen-tool object and the drawing paper (see Yeh et al, 2002) to be implemented in the prototype.

Besides focusing on visual elements for future work, sound is another modality that should be considered to enhance user experience of a computer drawing interaction. Artist 15 said: *"I think when you draw, you are not just drawing, onto the paper; drawing with smell, and sound."* During the evaluation study several artists noted the noise made by the PHANToM during their interactions. Artist 11 commented on the sound of the PHANToM motor as described in Section 7.8.1. Artist 17 whilst using 3H pencil on smooth paper in Interface 2 exclaimed: *"Wow! It is like something, the motor is making me feel like distracted, but I think I know why it feels like this. This feels like drawing on sandpaper, actually."* This artist further commented on 'felt-tip' on 'smooth paper' by saying: *"The hand perceive it; this pen makes like the squeaky sound and feels the same in the hand."* When using 'charcoal' on 'smooth paper' in Interface 2, Artist 9 expressed: *"That's very similar too (laugh). That's gritty. Even that noise (laugh); that's really like charcoal."* Similarly, Artist 20 said: *"This one is like in charcoal; like you can even hear the sound from the machine which sounds like 'eeee', like charcoal, you know when you draw. It sounds like charcoal."* There is evidence from the artists' responses that incorporating sound into haptic drawing could enrich user experience and needs to be further investigated.

Another recommendation for future research is to use a different haptic device for interactions. This would be useful if comparison of user haptic experience needs to be established when different haptic devices are employed. As described in Chapter 4, the PHANToM haptic device is more appropriate for interactions dealing with force feedback and not specifically for tactile sensation. If a haptic device suitable for supporting tactile feedback such as those involved in a drawing domain is employed, perhaps a different type of response in terms of users' haptic experience could be gathered. The choice of haptic device could also be selected among those that can support modality such as smell as highlighted specifically by Artist 15 in order to gain rigorous user experience.

The formulation of a haptic taxonomy for the drawing domain presented in Chapter 3 has been limited to a small collection of pen tools and drawing surfaces. Further work in terms of using various other drawing tools and surfaces could create more possibilities. This is to address some issues in the study findings presented in Chapter 7 where artists commented on the tactile sensation perceived during the drawing interaction. Perhaps, by having a wider choice of drawing implements, a larger vocabulary of tactile cues could emerge.

The studies presented in Chapters 3 and 7 involved mainly students from one art school. A different group of artists other than students chosen from one particular school may contribute to a differing vocabulary in terms of expressing the users' haptic experience. Minsky's three different ways of describing haptic sensation provides an approach to analyse the artists' haptic experience especially for first time users of PHANToM. Other than using a perceptual description as described in Section 7.9, the artists expressed haptic feedback perceived using cognitive explanations that comprise elements of semantics, metaphorical, functional, and affective (Section 2.2.2). This is presented in sections such as 7.7.3 in which a particular combination of haptic sensation was associated with a functional cognitive description such as carving with a stone (Artist 3). This type of description is also identified in other examples from the evaluation study. When referring to the tactile sensation in Interface 1, Artist 13 said: *"Every tool, every material is different; not in terms of the tools it self but how it interacts with the surface. It's the same with car tyres, I think. Well, back home we have -15 and +35 and the surface gets very different if it is very cold, if it is very hot as well. When the tyre gets very hot and one is very cold; and this, it is different as well; and how the feeling on the steering wheel is different as well. It is easier to have a softer tyre. And it is the same here."* Artist 19 expressed his haptic experience interacting with a combination in Interface 3: *"This is something like, a rainy day; getting all water; all soaked up; walking home."* These responses raise questions revolving the factors that trigger artists in making such comments. If these factors are identified and taken into consideration, perhaps there is a tendency for a particular haptic drawing interface to be preferred by users. This needs further investigation.

This thesis has investigated users' haptic experience and interface designs in a drawing environment. Research was presented on investigating users' preference towards two haptic interface design options suitable for a drawing application. The findings suggest that both designs have potential to be accepted by users as the haptic interfaces assist in fostering the sense of being enjoyable during an interaction. Future work will need to make central the subjective perceptions and experiences of artists for a richer user haptic experience in a drawing application.

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Appendices

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HAPTIC CUES FOR SUPPORTING INTERACTION DESIGN IN THE DRAWING DOMAIN

Suziah Sulaiman & Ann Blandford
UCL Interaction Centre
University College London
London WC1E 7DP
{S.Sulaiman, A.Blandford}@ucl.ac.uk

ABSTRACT

This paper presents a study to identify a set of haptic cues for the drawing domain. The study involved 21 traditional artists using various pen-like tools and describing the tactile sensation felt when drawing. The study has identified a set of haptic features perceived in the real world situation, which will be used to inform the design of haptic cues to be implemented within a novel drawing application. A set of visual features associated with these haptic cues has also been established. This study provides a systematic empirical account of haptic cues for drawing that has previously been lacking from implementation-oriented work in this domain.

Keywords

Haptic interactions, haptic feedback, tactile cues, creative process, multimodal interaction, user experience

1. INTRODUCTION

A creative activity such as drawing usually exploits both visual and haptic (touch-based) modalities. The mark produced and seen on the paper is a result of the kinaesthetic act of drawing by the artist. To an artist, the process of creating an artwork is often as important as the product itself [6]. There is a growing awareness among interface designers of the value of haptic feedback in enhancing the user experience [1,6].

Recent advances in the development of haptic devices have also facilitated the integration of haptic feedback for interactions. Using a pen-based haptic device, an artist can work more naturally than using a simple stylus for creative work [1]. A number of studies have reported that haptic interfaces can improve users' performances and enhance their creative processes [1,4,8,10]. However, little work has related artists' experience with traditional drawing tools to the design of haptic interfaces. That is the focus of the work reported here.

In this paper we focus on the domain of drawing, a fundamental sub-domain of Art. We examine the importance of haptic feedback in interaction design and identify the main haptic cues in the drawing domain, with a view to supporting the creativity of users. We present a study whose primary finding is a structured set of haptic features for the drawing domain. We discuss the implications of these haptic features in supporting the design of creative artwork.

2. BACKGROUND

Haptic feedback is an important, but as yet under-explored, design element in human-computer interaction [7]. Its integration could benefit many computer-based applications in areas such as medical training, 3D modelling and entertainment. The feedback received during interactions provides information about an object's surface texture, shape and weight. This information enhances the sense of realism in a computer environment [1].

2.1 Studies in Haptic Interface Design

There are two broad areas of study pertaining to haptic interface design. The first, more dominant, area involves applying haptic feedback for interactions [1,3,4,6,9,10]. In this area, information obtained from the psychophysics field plays an important role. Interface designers use findings on how people perceive and manipulate active and passive exploration of touch [5] to simulate haptic behaviour for interactions. The second area involves the creation of successful interactions [7,8]; this typically takes a "top-down" approach, addressing particular aspects of physical interaction in the real world [7]. An example of this type of study is that of understanding multimodal virtual environments, specifically the haptic modality, to support creative processes [8].

2.2 Applying Haptic Feedback For Interactions

Haptic feedback has been investigated in a range of applications, including the art-related context been considered here, and also areas such as medical training and systems for blind users.

2.2.1 Art-related Applications

Force feedback has been used in painting applications to give users natural control of complex brush strokes [1,6].

In one such application [1], when users apply force they obtain tactile cues to the pressure being applied. These cues enable the users to manipulate the paintbrush better. Other tactile cues received can include the smoothness, stiffness and stickiness of brush strokes [6]. Another study has reported that users can edit a painting and feel the material properties in a natural way [4]. In that study the users could paint directly on a 3D model and could sense the thickness variation due to the added paint. They could feel the local material properties such as friction and stiffness of the interactions. Haptic feedback is also used in an interactive system for digital Chinese painting [10]. In this application, users could feel the viscosity, friction and bending force of the brush touching the paper.

2.2.2 Other Applications

As well as being used in art-related domains, haptic feedback has been used for blind users [9]. In this case, two haptic properties, friction and stiffness, were compared to check their suitability for representing graphical data and it was found that friction was a better candidate. A study in a medical application [3] used haptic feedback to train medical students to discriminate an object (an ovary) through the softness of its surface texture. Haptic feedback was also used to determine the size and location of the object.

2.3 Motivation For The Study

Despite being useful, the haptic cues in the applications described above have been found to be insufficient for users [2]. This hinders the users' interpretation of the virtual haptic world they are interacting in. In such cases, multimodal interactions are usually considered, in which haptic feedback is combined with visual, audio or visual and audio cues [1,2,3,4,6,10]. Even though there have been many attempts to include haptic cues such as softness [1,3], hardness [1] and stiffness [4,9] in the interface design, the integration is still not clear in terms of how these cues are chosen and when they should be applied for interactions. Consequently, the role of haptic cues is poorly understood. More work is still needed to understand and exploit the capabilities of haptic cues in multimodal interaction.

Integrating haptic cues is particularly challenging because the haptic modality is very context dependent, so that the choice of haptic feedback depends on the domain one is working in [3,9]. A different domain of applications requires a different set of haptic cues to enable users to discriminate the haptic effect well. To design useful haptic feedback for creative drawing, it is necessary to investigate possible haptic cues – in the form of tactile information – for the drawing domain.

There is currently a gap in terms of understanding the haptic cues in the drawing domain. We are filling this gap by providing a clear framework which integrates haptic cues for interactions

3. THE STUDY

This study was designed to identify tactile features that are significant in the drawing domain. The main objective of the study was to compile a structured vocabulary of users' experience when using drawing tools, focusing on the haptic properties and features of the drawing domain. In addition, the visual cues related to the tactile sensation while drawing were also examined in this study.

3.1 Method

21 traditional artists took part in the study (13 females and 8 males). 2 of the artists paint for living, while the rest were 15 undergraduate and 4 postgraduate students from the Slade School of Art at University College London.

All the artists were interviewed and the conversations were audio recorded. During the interviews, the artists were given a collection of 9 pen-like tools consisting of 4 pens, 3 pencils, a crayon and charcoal to work with. They were asked to describe the tactile sensation and the visual appearance of the tool while holding it in their hands. Using the tool, they were asked to do free drawing or writing on two different types of textured paper. During their interactions, they were asked to talk out loud about the tactile sensation they experienced and the appearance of the mark produced when they used each tool and paper. They were also encouraged to talk about any similar experiences using drawing tools in their daily work.

3.2 Data Analysis

The recorded conversations were transcribed to obtain 21 sets of data, each of which contains information on an individual artist's experience using the tools. From each set, the vocabulary that was used by the artist was identified. These vocabularies were examined to identify the terms used by each artist across all the 9 pen-like tools and two paper types. From the 21 sets of data, any similar terms were grouped under the same category. The groups obtained were further classified into a higher level based on the actions made by the artists during the study, so as to determine at which stage of interactions a particular haptic cue should be applied in the interface design.

To ensure consistency of the terms used by the artists when describing each tool, an orthogonal data analysis was performed. In this, the transcribed data was transformed into 9 different sets based on the tools used in the study. The terms used by all the 21 artists to describe the tactile sensations when using each tool were identified. These terms were cross-examined to assess their consistency with the earlier groups. No major inconsistencies were found.

A similar approach was taken for identifying the related visual cues.

3.3 Study Results

The data analysis has resulted in two inter-related sets of information on the haptic and visual elements. In this study, both sets of elements were classified and presented based on the interactions involved in the drawing domain.

3.3.1 Haptic Elements for the Drawing Domain

The properties and features of the haptic cues identified are presented in Figure 1. There are three main types of interactions that involve the sense of touch. The 'hand and tool' interaction occurred when the artists described the tactile sensation while holding the tool. The 'tool and surface' interaction occurred when the tool touched the surface of the paper, as the artists were drawing or writing, and the 'hand and surface' was when the artists used their own fingers to smudge the mark on the paper.

Type of Interaction	Action	Properties	Features	
Hand & Tool	Hold	Surface texture (tool)	Smooth	Bumpy
			Soft	Hard
			Slippery	Plasticky
			Rubbery	Metallic
		Shape	Short	Long
			Thin	Thick
			Round	Sided
		Weight	Light	Heavy
		Temperature	Cold	Warm
		Grip	Slipping	Not slipping
Tool & Surface	Press	Surface texture (tool)	Soft	Hard
			Sticky	Dry
	Push	Surface texture (paper)	Smooth	Rough
		Friction	Soft	Hard
			Sticky	Dry
			Waxy	Powdery
			Smooth	Glide
			Flows	Silky
			Velvety	Creamy
			Stiff	Sharp/ scratchy
			Bumpy/ rough	
Hand & Surface	Smudge	Surface texture (tool & paper)	Soft	Rough

Figure 1: Properties & Features of a Haptic Domain

The action "hold" relates to the first type of interaction. When holding the tool, the haptic properties that could be assessed were the *surface texture*, *shape*, *weight*, *temperature* and *grip* of the tool. For the *surface texture* property, the artists commented on the smoothness, hardness, slipperiness and material of the tool. They noted the *shape* of the tool in terms of its length, width and roundedness, and the *weight* in terms of its heaviness. The *temperature* of the tool was noted in terms of its coldness and the *grip* of its slipperiness.

The second type of interaction involves two main actions made by the artists: "press" and "push". In this analysis the action "press" is considered as a passive touch [5]. It occurred immediately after the tool touched the paper and the artist could feel the *surface texture* property of the tool; this could be 'soft', 'hard', 'sticky' or 'dry'. It also happened when the artists made 'dotted patterns' on the paper. In contrast, the action "push" involved active haptic exploration [5]. The artists applied force and made a mark on the paper. The "push" action provided information about the *surface texture* of the paper. It also produced a *friction* property between the tool and the paper, resulting in features including all those noted under the "press" action and also other cues such as 'smooth', 'glide', 'stiff', and 'sharp/ scratchy' (see Figure 1 for a full list).

The third type of interaction involved the artists smudging the mark with their fingers ("tool"). They could feel the properties of the *surface texture* of the paper while interacting with the "tool".

3.3.2 Visual Elements for the Drawing Domain

The haptic properties for the drawing domain are closely related to the visual cues perceived. The tactile cues may correlate to the visual appearance of the mark; for example, a 'stiff' sensation during drawing or writing may produce a 'shaky' or 'agitated' line. The properties and features of the visual domain are shown in Figure 2.

Type of Interaction	Object	Properties	Features
Pre - Interaction	Nib	Shape	Sharp/ pointed Blunt
			Thin Wide
	Shaft	Shape	Thin Chunky
			Round Angular
		Surface texture	Smooth 'Blobs'
		Appearance	Colour Shiny
			Material
	Paper	Surface texture	Smooth Textured
			Glazed
		Thickness	Thin Thick
Post – Interaction	Line	Pressure Mark	Clean/ Precise/ Definite
			Uniform/ continuous
			Delicate Soft Light
			Distorted Even Jagged
			Shaky/ agitated Broken
			Fuzzy/ blurry Uneven
			Blotchy/ messy Smudgy
			Harsh Strong
			Thin/ small Thick/ heavy
			Black (ink) Blue (ink)
			Dark Bold Black
			Bumpy Rough Grainy
			Dry Watery Shiny

Figure 2: Properties & Features of a Visual Domain

In analysing the visual effect, two different stages of interactions that involve visual sense were established. As shown in Figure 2, the first stage is called the "pre-interaction". This occurs before the drawing or writing activities. The appearance of the nib and shaft of the tools and the surface of the paper were observed. The nib has a property *shape* which refers to the sharpness and thickness of the tip. The observable shape of the nib is expected by the artists to allow them to anticipate the different types of marks that will be created when friction is produced during drawing or writing.

The shaft of the tool has visual properties pertaining to its *shape*, *surface texture* and *appearance*. The *shape* of the shaft includes its thickness and roundedness, the *surface texture* its smoothness, and the *appearance* its colour, material and shininess. The visual shape of the shaft – for example, 'chunky' – is expected to correlate to the (felt) weight of the tool.

The appearance of the paper has properties of *surface texture* and *thickness*. The *surface texture* is said to be 'smooth', 'textured' or 'glazed', while the *thickness* could be either 'thin' or 'thick'. These visual features are expected to influence the haptic *surface texture* and the tactile sensation felt from the *friction* that occurs when the action "push" takes place during drawing or writing.

The second stage is called the "post-interaction". This is when the writing and drawing activities have been performed. At this stage the appearance of the line is observed. The line is examined for its *pressure mark* properties. The features associated with this property include 'uniform' or 'continuous', 'delicate', and 'distorted' (see Figure 2 for a full list). These features are expected to be the result of the friction produced during the interaction between pen-like tool and paper. For example, the feature 'smooth' of property *friction* in Figure 1 may produce a 'uniform/continuous' line in Figure 2. Similarly, the 'bumpy/rough' feature may produce a 'distorted' line.

4. DISCUSSION AND FURTHER WORK

The study has revealed the vocabularies of haptic and visual features for the drawing domain. If a similar study was conducted with additional tools and paper types, it is likely that the vocabularies would expand slightly; however, this study has identified much of the possible space and – we believe – the important higher level categories in terms of interaction types, objects, actions and properties. We also believe that our categorisation of haptic cues is the first of its kind. The two aspects that can inform interface design most directly are the stages of interaction and the haptic properties and features.

4.1 Stages of Interactions in the Drawing Process

The systematic approach taken towards relating haptic features to user actions in the drawing process has shown which haptic cues to apply in interface design for particular user actions, so that appropriate haptic feedback can be provided to the users. For example, as shown in Figure 1, the haptic cues for the actions "press" and "push" include 'soft', 'hard', 'sticky' and 'dry'. It is also important to distinguish the features of the *surface texture*, especially since this property affects every action made in Figure 1.

4.2 Haptic Properties and Features

A hierarchical representation of haptic cues, in terms of the properties and their features, is explicitly presented. The level of details enables an interface designer to distinguish between the set of tactile properties and their features. The categorisation of haptic cues also delineates the range of features for a particular haptic property. For example, the property *friction* in Figure 1 has a wide selection of features ranging from 'glide' to 'stiff'.

4.3 Further Work

This study is the first step in developing and testing a drawing tool that can support the creative processes of artists by providing appropriate haptic feedback within their interactions with digital tools. Prior to system development, further clarification of the association between the features of the haptic and visual modalities is needed. Implementation and evaluation work is planned in which the haptic and visual cues will be integrated in system design.

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Instructions for Evaluators – Study 1

January 2004

"Pen-like Tools for Drawing & Writing": General Information

Thank you for volunteering to participate in this study. This is one in a series of studies aimed at evaluating pen-like tools such as pens, pencils and brushes.

The aim of this study is to understand the experience of using pens and pencils for drawing and writing. You will be asked some general questions regarding pens and pencils that you have used before. Then, you will have to perform some simple drawing and writing using a collection of pens and pencils.

The whole study takes about 45 minutes. Please say out loud your experience when using these tools during the study.

Please be informed that the conversation in this study will be recorded. We can assure you that the recorded information will be strictly used for the purpose of this study only.

Please feel free to ask questions pertaining to this study. While the researcher will be happy to answer any general questions you may have, s/he has been instructed not to discuss some aspects of the study until the end.

You will be given a Consent Form pertaining to this study very shortly. Please read and sign the form.

Thank you.

UCLIC

University College London
Remax House, 31-32 Alfred Place
London WC1E 7DP
United Kingdom

Tel: <02076795225> email: <s.sulaiman@ucl.ac.uk>

Identification Number for this test:

CONSENT FORM

Title of Study: **"Pen-like" Tools for Drawing& Writing**

Please tick box

1. *I confirm that I have read and understood the information sheet dated...................... for the above study and have had the opportunity to ask questions.* ☐

2. *I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason, without my legal rights being affected.* ☐

3. *I agree to take part in the above study.* ☐

____________	____________	____________
Interviewee name	*Date*	*Signature*
____________	____________	____________
Researcher	*Date*	*Signature*

Appendix 3-4

Details on Pen Tools and Paper Type

PEN TOOL

Pen-like Tool Code	Description of the Tools
PN 1	Roller-ball pen (Bacha & Bacha, London)
PN 2	Ballpoint pen (WHS Stick BP Fine Blue) – body with grip
PN 3	Felt-tip pen (Berol 0.6mm Handwriting Pen)
PN 4	Ballpoint pen (WHS Fine Blue) – sided body
PCL 5	3H Pencil (Grip 2001 3=H)
PCL 6	Graphite Pencil (REMBRANDT – Grafit Aquarell 501/HB)
PCL 7	(2B Lead) Parker Mechanical Pencil (Silver)
CR 8	Crayon
CHAR 9	Charcoal

DRAWING PAPER

Code	Description of the Tools
'Smooth'	A4 paper
'Textured'	Watercolour paper

A Sample of Higher Level Groups Formulated from the Features of Haptic Perception When 'Push' Action in a Drawing Interaction (for Subject #1-21)

Features	Feature ['New Group']	Justification
Very tactile	SMOOTH	(PCL5, #16)
Quite smooth		(PN2, PN1 #1); (PCL7, #2); (PN1, PN2, #3); (PN1, PCL7, #4); (charcoal – rough paper, PN3 – rough paper, #10); (PN1, #15); (PCL5, PN1, #16); (PCL7, PN2, #18); (crayon, #17)
Smooth		(PCL6, #3); (crayon, #4); (PCL6, #5); (PN3, #1); (crayon, PN3, PN1, PN2, #7); (crayon, charcoal, PN1, PCL6, #8); (PCL5, #10); (PN4, PN2, #6); (PCL5, PCL7, charcoal, #11); (PN1, PN3, PCL7, charcoal, #12); (PN4, PCL7, #14); (PCL7, #15); (#11); (PCL7, #16); (PN2, #17); (PCL7, #19); (PN2, #21); (PN3 – indirect, #18); (#20)
Very smooth		(PCL6, #4); (crayon – indirect – rough paper, #2); (crayon, charcoal, #5); (PN2, PCL6, PN3, charcoal, PCL7, crayon, #10); (PCL7, #7); (PCL6, #8); (PCL6, #16); (PCL7, crayon, PN2, PCL6, #19); (PN1, #21); (PN1, PN2, PCL7, #17); (#18)
Pretty smooth		(PN1, #10); (PN1, #19)
Not that smooth		(PN1 – rough paper, #15)
Incredibly smooth		(crayon, #10)
Really smooth		(PN2, #4)
Really, really smooth		(PCL6, #11)
Not as smooth as		(PCL5, #2); (charcoal, #11); (PN2, #13); (PN1, #18)
Smoother		(PN2, #8); (crayon-rough paper, #9); (crayon – rough paper, #18)
A lot smoother		(PN2, crayon, #19); (#18)
Smoothest		(charcoal, #19)
More smooth		(charcoal, #14)
Too smooth		(PCL7 – rough paper, #14)
Not too smooth		(PN4, #3)
Steady resistance	FLOWS	(PCL7, #5)
Move very easily		(PN1, #14)
Flows more easily		(PCL5 – r, #5)
Flows very easily		(PN3, #13)
Flows very, very easily		(PN2, #8)
'Very flowy'		(crayon, #15)
Flowy		(#20)
'It flows'		(PN3, #20)
Flows very well		(PN2, #17)
Uniformly		(PN1, #4)
Very light		(charcoal, #19)
'Continuous writing'		(PN2, #14)
Light		(PN4, PCL7, PN3, #14)
Really, really light		(charcoal, PCL7, #13)
Flows quite well		(PN2, #2)
Glide	GLIDES	(PN2, #5); (crayon, #16); (PCL7, #17); (PN2, #18); (PCL6, crayon, #19); (#18); (PN3 – indirect, #18); (crayon, #15)
'Glides on the surface'		(PCL6, #11)
Gliding		(PN2 – rough paper, #18)
Quite glidy		(crayon – rough paper, #16)
Too sliding		(PN1, #12)
Slide along		(PN4, #13)
Slide well		(PN4, #13)
'Like silk'	SILKY	(PCL7, #17)
Silky		(crayon, #7); (PN1, #16)
More silky		(PCL6, #6)
'A little bit like velvet' = 'velvety' = 'has gravity'		(PN1, #10)

Velvety	**VELVETY**	(charcoal, #10); (PN3, #17)
Very velvety		(crayon, #10)
Quite velvety		(PN2, #10)
Creamy	**CREAMY**	(crayon, #16)
Slightly creamy		(PN2, #10)
Has a gravity		(PN2, #10)
Less friction	**STIFF**	(PCL7, #1)
More friction		(PN4, #3)
'The ball doesn't want to roll'		(PN4, #18)
Don't scratch		(PCL7- rough paper, #12)
'Stuck'		(PN1/ rough paper, #7)
'More resistance'		(charcoal-rough paper, #7)
Block		(PN2, #9)
Not too free flowing		(PN1, #10)
Stiff		(PCL5 – rough paper, #19)
Pretty stiff		(PCL5, #19)
Really stiff		(PN4 – rough paper, #19)
Very stiff		(PN4 - indirect, crayon, #19)
'Little restricted by the texture'		(PCL6 – rough paper, #19)
'Has a certain amount of resistance'		(PCL6 – rough paper, #18)
'Goes into the grooves of the paper & it stops'		(PN1 – rough paper, #21)
'The paper is getting in'		(PCL7 – rough paper, #21)
(Resistance) Putting in		(PN2, #1)
Vague vibration		(PCL5, #1)
Not scratchy		(PN1, #16)
Not gliding		(crayon-rough paper, #4)
Doesn't flow as easily		(PN1 – rough paper, #10)
Doesn't flow		(PN4, #16)
'Ink doesn't flow'		(PN1, #20)
'Didn't flow'		(PN2 – indirect, #20)
Creamy feeling is gone		(PN2 – rough paper, #10)
Not velvety		(PN3 – rough paper, #17)
Velvety feeling is gone		(PN2 – r, #10)
'cut into the paper'	**SHARP/ SCRATCHY**	(PN1, #9)
'Cut in the paper'		(PCL7 – indirect, #11)
Slicing into the paper		(PCL7, #13)
Cutting into the paper		(PCL5, #15)
Drag		(PN4, #7)
Too sharp		(PCL5, #14)
Scratchy		(PCL5, #4); (PN4, #8); (PCL5, #10); (PN3, #11); (PN4 – rough paper, #16); (PN3, #18)
More scratchy		(PN2-rough paper, PN4 – rough paper, #10)
Slightly scratchy		(charcoal, #10); (PN3, #16)
Scratch		(PN4, crayon, #9); (PN4, #12); (PCL5, #14)
Quite scratchy		(PN4, #10); (charcoal – rough paper, #15); (PN4, #16); (PN3, #16)
'Not really scratchy'		(PCL6, #10)
Scratches		(PN4, #5); (PN1 – indirect, #16); (PCL7 – the nib w/out lead, #20)
Scratchiness		(PN1 – rough paper, #21); (PN3, #16)
A bit scratchy		(PN3, #18)
Less scratchy		(PN3 – rough paper, #18)
Very scratchy		(PN4, #16)
Completely scratchy		(PN3 – rough paper, #16)
Very scratchy		(PCL5, #4); (PCL6 – rough paper, #10)
Scrapping		(PN3, #4)
Dragging		(PN2, PN4, #4)
Crisp		(PN2, #14)
Sharp		(PCL5, #4); (PCL5, #15)

Bumpy	BUMPY/ ROUGH	(crayon, #12); (PN1, PN2-rough paper; PN4-rough paper, PN3-rough paper, charcoal, crayon#10); (PN2, PN4 – rough paper, #12); (PN1 – rough paper, PCL6, #15); (PN1 – rough paper, #16)
Not as smooth as		(PN2 –r, #6); (PN2 – rough paper, #21)
Not even		(PN2, #9); (PN1, #15)
Feel the bump		(PN1, #10)
Uneven		(PN4, #15)
Jump		(charcoal, #11)
Jump up & down of the line		(PN3 – rough paper, #11)
Quite bumpy		(PCL7 – rough paper, #15)
Too bumpy		(PCL7 – rough paper, #12)
'On a cobbled street'		(PN1 – rough paper, #16)
A little bit rough		(PN1, #18)
Very coarse		(PN4, #17)
Coarse		(PN1, #17)
Not that coarse		(PN4 – rough paper, #17)
Rough		(PN4, #9); (PCL6, #15)
Quite rough		(PCL5, #12)
'Distorting the line'		(PN2, #7)
Wobbly		(PN2, #7)
Not bumpy		(PCL7, #12)
Waxy	WAXY	(crayon, #2); (crayon, #11); (crayon, #15); (crayon – rough paper, #20)
Quite waxy		(crayon – indirect, #17)
Sticky	STICKY	(crayon, #3
Oily		(crayon, #17)
More moisture		(PN3, #9)
Very wet		(crayon, #17)
Not sticky	DRY	(crayon-r, #3)
Dry		(charcoal, #11); (PN2 – indirect, #20)
Quite dry		(PN2 – indirect, #18)
Very dry		(charcoal, #4); (charcoal, #11); (crayon – indirect, #17)
Dust		(charcoal, #12)
Powdery	POWDERY	(#18)
'Squishy'	SOFT	(crayon, #13)
'There is suspension'		(PN2, #6)
Soft		(crayon, #5); (charcoal, #6); (PCL7, PCL6, #13); (PN3, #14); (crayon, PCL7, #15)
So soft		(crayon, #20)
Softer		(PCL6, #5); (PCL6, PN2, #6); (PCL6 – rough paper, #18)
Very soft		(PCL6, #4); (PCL7, #15), (PCL7, #14); (PCL6, #16)
A bit too soft		(PCL6, #9)
Quite soft		(PCL7, #5); (PCL6, #10); (PCL7, #15)
Delicate		(PCL6 - indirect, #10); (PN1 – indirect, #18)
Really not soft	HARD	(PCL5 – rough paper, #13)
Hard		(charcoal, #6); (PCL5, #18); (PN4, #19); (PCL5, PN4, PN2 – indirect, #20); (PCL5 – rough paper, #21)
Quite hard		(PN4, #6); (PCL5, #11); (PCL5, #18)
So hard		(PCL5, #9)
Harder		(PCL5, #9)
'Doesn't sink into the paper'		(PN4, #14)
Pretty much on top of the paper		(PN1, #19)

Extraction of findings on tactile and visual cues from the 'paper-surface and pen-like tools' study result

Tactile and Visual Cues When Using Pen-Like Tools on a SMOOTH Paper

Note: numbers in brackets indicate the number of artists who used the terminology						
			PRESS		**PUSH**	
			Tactile	Visual	Tactile	Visual
PENCIL	Thin tip	PCL5	Hard (2)	Light	Hard (9)	Light (10)
				Delicate	Smooth (5)	Thin/small(6)
				Smooth	Sharp/scratchy (4)	Delicate(2)
					Stiff (2)	Smooth(2)
					Bumpy/rough (2)	
		PCL7	Soft (3)	Thin/small	Smooth(12)	Smooth(9)
				Light	Flow(5)	Thin/small(7)
				Soft	Soft(3)	Dark(6)
					Glide(1)	Light(3)
					Silky(1)	Thick/heavy(3)
						Uniform(2)
						Soft(2)
						Black(1)
	Wide tip	PCL6	Soft (5)	Thin/small	Smooth(9)	Thick/heavy(9)
				Soft	Soft(6)	Dark(5)
					Glides(4)	Light(5)
					Silky(1)	Bold(4)
						Distort(4)
						Soft(4)
						Thin(3)
						Black(3)
						Smooth(2)

Tactile and Visual Cues When Using Pen-Like Tools on a SMOOTH Paper (Continued)

			PRESS		PUSH	
			Tactile	Visual	Tactile	Visual
PEN	Thin tip	PN4	Hard(1)	Light	Sharp/scratchy(7)	Thin/small(8)
				Thin/small	Hard(4)	Light(7)
					Stiff(3)	Strong(3)
					Bumpy/rough(3)	Dark(3)
					Smooth(3)	Distort(2)
						Thick/heavy(1)
		PN3	Soft(2)	Light	Smooth(5)	Smooth(5)
				Watery	Flows(5)	Thin/small(5)
					Soft(2)	Thick(4)
					Velvety(1)	Distort(4)
					Scratchy(3)	Uniform(4)
					Sticky(2)	Dark(3)
						Strong(2)
						Light(2)
						Watery(1)
						Bold(1)
						Black(1)
	Wide tip	PN1	Soft(3)	Light	Smooth(13)	Uniform(4)
					Flows(2)	Thick/heavy(4)
					Glides(1)	Light(4)
					Velvety(1)	Smooth(3)
					Silky(1)	Thin/small(3)
						Bold(2)
						Strong(2)
						Dark(1)
		PN2	Soft(2)	Light	Smooth(11)	Dark(4)
					Flows(6)	Smooth(3)
					Glides(2)	Light(2)
					Soft(3)	Thin/small(2)
					Velvety(1)	Uniform(2)
					Creamy(1)	Thick/heavy(2)
					Sharp/scratchy(2)	Dry(1)
					Stiff(1)	Shiny(1)
CRAYON		CR8	Sticky(7) Soft(6) Dry(2)	Light	Smooth(6)	Thick/heavy(9)
				Soft	Flows(4)	Distort(3)
				Thin/small	Stiff(3)	Bold(3)
					Glides(2)	Black(3)
					Velvety(1)	Dark(2)
					Creamy(1)	Smooth(2)
					Silky(1)	Thin/small(2)
					Sharp/scratchy(1)	Soft(1)
						Light(1)
						Strong(1)
CHARCOAL		Char	Dry(9) Soft(2)	Thin/small	Smooth(8)	Black(5)
					Rough(1)	Distort(5)
					Velvety(1)	Dark(4)
					Hard(1)	Thick/heavy(4)
					Sharp/scratchy(1)	Thin/small(3)
						Smooth(2)
						Strong(1)
						Bold(1)

Tactile and Visual Cues When Using Pen-Like Tools on a TEXTURED Paper

Note: numbers in brackets indicate the number of artists who used the terminology						
			PRESS		**PUSH**	
			Tactile	Visual	Tactile	Visual
PENCIL	Thin tip	PCL5	Hard (2)	Light	Hard (5)	Light (5)
				Delicate	Bumpy/rough (3)	Smooth (3)
				Smooth	Stiff (2)	Distort (1)
					Flows (1)	Soft (1)
					Sharp/scratchy(1)	Thin/small (1)
						Thick/heavy (1)
						Dark (1)
		PCL7	Soft (3)	Thin/small	Sharp/scratchy (4)	Dark (2)
				Light	Smooth (2)	Thin/small (2)
				Soft	Bumpy/rough (3)	Smooth (2)
					Stiff (1)	Distort (2)
						Thick/heavy (1)
						Light (1)
	Wide tip	PCL6	Soft (5)	Thin/small	Soft (5)	Distort (4)
				Soft	Stiff (2)	Thick/heavy (4)
					Glide (1)	Black (3)
					Bumpy/rough (1)	Dark (2)
						Light (2)
						Soft (2)
						Grainier (1)
						Shiny (1)
						Bold (1)
						Broken (1)
PEN	Thin tip	PN4	Hard(1)	Light	Sharp/scratchy (5)	Light (4)
				Thin/small	Bumpy/rough (4)	Distort (4)
					Hard (2)	Thin/small (2)
					Stiff (2)	Delicate (1)
					Smooth (1)	Bold (1)
		PN3	Soft(2)	Light	Sharp/scratchy (4)	Light (6)
				Watery	Bumpy/ rough (3)	Distort (4)
					Stiff (2)	Dark (3)
					Smooth (2)	Smooth (3)
						Thick/ heavy (3)
						Strong (3)
						Thin/ small (2)
						Broken (1)
						Bold (1)
	Wide tip	PN1	Soft(3)	Light	Stiff (5)	Light (3)
					Bumpy/rough (3)	Distort (3)
					Scratchy (1)	Soft (2)
						Thin/small (2)
						Bold (1)
						Thick/heavy (1)
						Dark (1)
		PN2	Soft(2)	Light	Bumpy/rough (5)	Distort (4)
					Sharp/scratchy (3)	Light (3)
					Stiff (1)	Thick/heavy (2)
						Bold (2)
						Dark (1)

Tactile and Visual Cues When Using Pen-Like Tools on a TEXTURED Paper (Continued)

Note: numbers in brackets indicate the number of artists who used the terminology						
			PRESS		PUSH	
			Tactile	Visual	Tactile	Visual
CRAYON		CR8	Sticky(7) Soft(6) Dry(2)	Light	Smooth (4)	Thick/heavy (4)
				Soft	Bumpy/rough (4)	Broken (3)
				Thin/small	Glides (3)	Dark (2)
					Soft (1)	Black (2)
					Velvety (1)	Rough (2)
					Dry (1)	Distort (2)
						Soft (1)
						Bold (1)
						Uniform (1)
						Grainier (1)
						Thin/small (1)
						Light (1)
CHARCOAL		Char	Dry(9) Soft(2)	Thin/small	Dry (4)	Distort (4)
					Smooth (3)	Light (2)
					Bumpy/ rough (3)	Thin/small (1)
					Sharp/scratchy (1)	Broken (1)
					Stiff (1)	Soft (1)
						Rough (1)
						Grainier (1)
						Dark (1)
						Black (1)

Appendix 3-7

Describing the Haptic Dimension Cues

In the context of drawing or sketching, can you describe (by using pictures, words or both) what the following dimension cues mean to you?

"Smoothness"

"Stickiness"

"Bumpiness"

"Scratchiness"

Vocabularies of Tactile cues for Card Sorting Task

Note:
These vocabularies were obtained from a study with a group of traditional artists interacting using pen-tools on different paper-types for drawing.

Index	Tactile Cues
1	Bumpy
2	Chalky
3	Coarse
4	Creamy
5	Crisp
6	Dragging
7	Dry
8	Flat
9	Flow
10	Glide
11	Grainy
12	Hard
13	Oily
14	Powdery
15	Rough
16	Rubbery
17	Scraping
18	Scratchy
19	Sharp
20	Silky
21	Slide
22	Smooth
23	Soft
24	Spongy
25	'Steady resistance'
26	Sticky
27	Stiff
28	Uneven
29	Velvety
30	"Waxy"

An Example of Program Codes

An example of a program code to illustrate the implementation of the bumpiness, stickiness, and scratchiness effects in a textual description metaphor interface design is as follows:

(i) Bumpiness (*rough; rough/ bumpy*)

```
void CMainFrame::OnBumpyLow()
{
        theCDrawGhostAppView->myDrawTool->BumpyButton = 1.0;

        theCDrawGhostAppView->Paper->SetAmplitudeX(0.1);
        theCDrawGhostAppView->Paper->SetAmplitudeY(0.1);
}


void CMainFrame::OnBumpyHigh()
{
        theCDrawGhostAppView->myDrawTool->BumpyButton = 2.0;

        theCDrawGhostAppView->Paper->SetAmplitudeX(0.2);
        theCDrawGhostAppView->Paper->SetAmplitudeY(0.2);
}
```

The 'low' and 'high' bumpiness could be implemented by taking the lowest and highest values of the amplitudes from the object-based metaphor design dataset, respectively.

(ii) Stickiness (*sticky, creamy, velvety*)

```
void CMainFrame::OnStickyLow()
{
        theCDrawGhostAppView->myDrawTool->StickyButton = 1.0;

        theCDrawGhostAppView->myPaperBase->setSurfaceFstatic( 0.40 );
        theCDrawGhostAppView->myPaperBase->setSurfaceFdynamic( 0.40 );
}

void CMainFrame::OnStickyMed()
{
        theCDrawGhostAppView->myDrawTool->StickyButton = 2.0;

        theCDrawGhostAppView->myPaperBase->setSurfaceFstatic( 0.75 );
        theCDrawGhostAppView->myPaperBase->setSurfaceFdynamic( 0.65 );
}

void CMainFrame::OnStickyHigh()
{
        theCDrawGhostAppView->myDrawTool->StickyButton = 3.0;

        theCDrawGhostAppView->myPaperBase->setSurfaceFstatic( 1.0 );
        theCDrawGhostAppView->myPaperBase->setSurfaceFdynamic( 0.9 );
}
```

The stickiness effect could be implemented by adjusting the static and dynamic coefficients friction obtained from the object-based metaphor interface design dataset. Like the method in implementing the bumpiness effect, the high and low stickiness values are taken from the combinations that have the highest and lowest friction values.

(iii) Scratchiness (hard, dry, stiff, sharp/scratchy)

```
void CMainFrame::OnScratchyLow()
{
        theCDrawGhostAppView->myDrawTool->ScratchyButton = 1.0;

        theCDrawGhostAppView->Paper->SetFrequencyX(200);
        theCDrawGhostAppView->Paper->SetFrequencyY(200);
}

void CMainFrame::OnScratchyMed()
{
        theCDrawGhostAppView->myDrawTool->ScratchyButton = 2.0;

        theCDrawGhostAppView->Paper->SetFrequencyX(4000);
        theCDrawGhostAppView->Paper->SetFrequencyY(2000);
}

void CMainFrame::OnScratchyHigh()
{
        theCDrawGhostAppView->myDrawTool->ScratchyButton = 3.0;

        theCDrawGhostAppView->Paper->SetFrequencyX(900000);
        theCDrawGhostAppView->Paper->SetFrequencyY(800000);
}
```

The scratchiness effect could be implemented by adjusting the frequencies of the X and Y-axis of the haptic paper surface obtained from the real world object-based metaphor interface design dataset. Like the method used in implementing the bumpiness effect, the high and low scratchiness values are taken from the combinations that have the highest and lowest combination of frequency values.

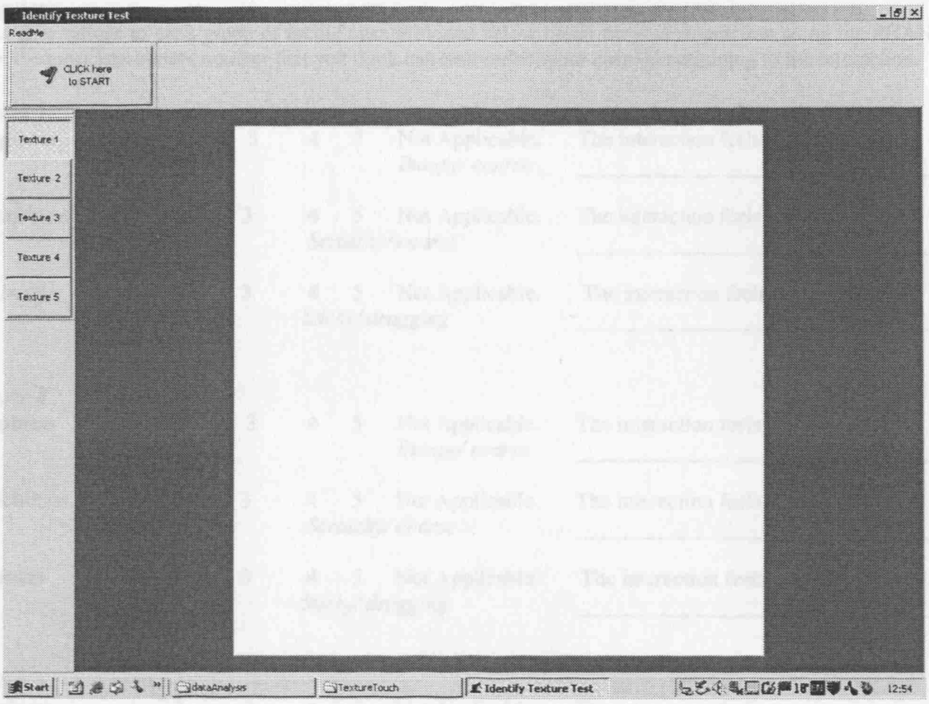
A Complete Dataset Used in the Formative Evaluation – The Second Version of the Interface Design Implemented

	Pen-tool	Friction		Stiffness	Damping	Amplitude	Frequency
		Static	Dynamic				
Smooth Paper	3H pencil	0.55	0.45	0.65	0.003	0.15	300
	2B pencil	0.46	0.45	0.50	0.002	0.10	250
	Graphite pencil	0.40	0.40	0.450	0.003	0.10	200
	Ball-point pen	0.60	0.475	0.65	0.003	0.15	350
	Felt-tip pen	0.75	0.65	0.50	0.003	0.1	300
	Roller-ball pen	0.50	0.50	0.475	0.003	0.10	250
	Crayon	1.0	0.90	0.50	0.0035	0.20	200
	Charcoal	0.50	0.46	0.620	0.003	0.20	300
Rough Paper	3H pencil	0.60	0.45	0.60	0.002	0.20	350
	2B pencil	0.50	0.45	0.625	0.003	0.20	325
	Graphite pencil	0.415	0.415	0.475	0.003	0.15	250
	Ball-point pen	0.60	0.50	0.625	0.003	0.20	375
	Felt-tip pen	0.50	0.475	0.60	0.003	0.20	350
	Roller-ball pen	0.525	0.50	0.615	0.003	0.20	350
	Crayon	0.90	0.80	0.50	0.0035	0.20	375
	Charcoal	0.50	0.470	0.610	0.003	0.20	350

A Revised Dataset used in the Formative Evaluation - The Third Version of the Interface Design Implemented

	Pen-tool	Friction		Stiffness	Damping	Amplitude		Frequency	
		Static	Dynamic			X-axis	Y-axis	X-axis	Y-axis
Smooth Paper	3H pencil	0.60	0.45	0.65	0.002	0.15	0.15	800,000	700,000
	2B pencil	0.46	0.45	0.50	0.002	0.10	0.10	250	250
	Graphite pencil	0.40	0.40	0.450	0.003	0.10	0.10	200	200
	Ball-point pen	0.60	0.50	0.65	0.002	0.15	0.15	900,000	800,000
	Felt-tip pen	0.75	0.65	0.50	0.002	0.10	0.05	6000	3000
	Roller-ball pen	0.50	0.50	0.475	0.003	0.10	0.10	250	250
	Crayon	1.0	0.90	0.50	0.002	0.20	0.20	200	200
	Charcoal	0.50	0.46	0.620	0.002	0.20	0.20	6000	6000
Rough Paper	3H pencil	0.60	0.50	0.60	0.002	0.20	0.20	700,000	700,000
	2B pencil	0.50	0.45	0.625	0.003	0.20	0.20	325	325
	Graphite pencil	0.415	0.415	0.475	0.003	0.15	0.15	250	250
	Ball-point pen	0.60	0.475	0.625	0.002	0.20	0.20	4000	2000
	Felt-tip pen	0.50	0.475	0.60	0.002	0.20	0.20	4000	2000
	Roller-ball pen	0.525	0.50	0.615	0.003	0.20	0.20	350	350
	Crayon	0.90	0.80	0.50	0.002	0.20	0.20	375	375
	Charcoal	0.50	0.470	0.610	0.002	0.20	0.20	3000	1000

A Sample of the Interface Design Used in the Formative Evaluation - First Part of Test 3



Rating Scale Questionnaire

PART I: Identification and rating Evaluator No: ______

Instruction:

Please give ratings to each group of tactile cues provided below based on your interaction using the PHANToM. Circle the most appropriate number that you think can best reflect your opinion pertaining to the interaction.

Texture 1

Bumpiness 1 2 3 4 5 Not Applicable. The interaction feels ...
Flow/ velvety *Bumpy/ coarse* ______________________

Scratchiness 1 2 3 4 5 Not Applicable. The interaction feels ...
Dry/ sharp *Scratchy/ coarse* ______________________

Stickiness 1 2 3 4 5 Not Applicable. The interaction feels ...
Flow *Sticky/ dragging* ______________________

Texture 2

Bumpiness 1 2 3 4 5 Not Applicable. The interaction feels ...
Flow/ velvety *Bumpy/ coarse* ______________________

Scratchiness 1 2 3 4 5 Not Applicable. The interaction feels ...
Dry/ sharp *Scratchy/ coarse* ______________________

Stickiness 1 2 3 4 5 Not Applicable. The interaction feels ...
Flow *Sticky/ dragging* ______________________

Texture 3

Bumpiness 1 2 3 4 5 Not Applicable. The interaction feels ...
Flow/ velvety *Bumpy/ coarse* ______________________

Scratchiness 1 2 3 4 5 Not Applicable. The interaction feels ...
Dry/ sharp *Scratchy/ coarse* ______________________

Stickiness 1 2 3 4 5 Not Applicable. The interaction feels ...
Flow *Sticky/ dragging* ______________________

Texture 4

Bumpiness 1 2 3 4 5 Not Applicable. The interaction feels ...
Flow/ velvety *Bumpy/ coarse* ______________________

Scratchiness 1 2 3 4 5 Not Applicable. The interaction feels ...
Dry/ sharp *Scratchy/ coarse* ______________________

Stickiness 1 2 3 4 5 Not Applicable. The interaction feels ...
Flow *Sticky/ dragging* ______________________

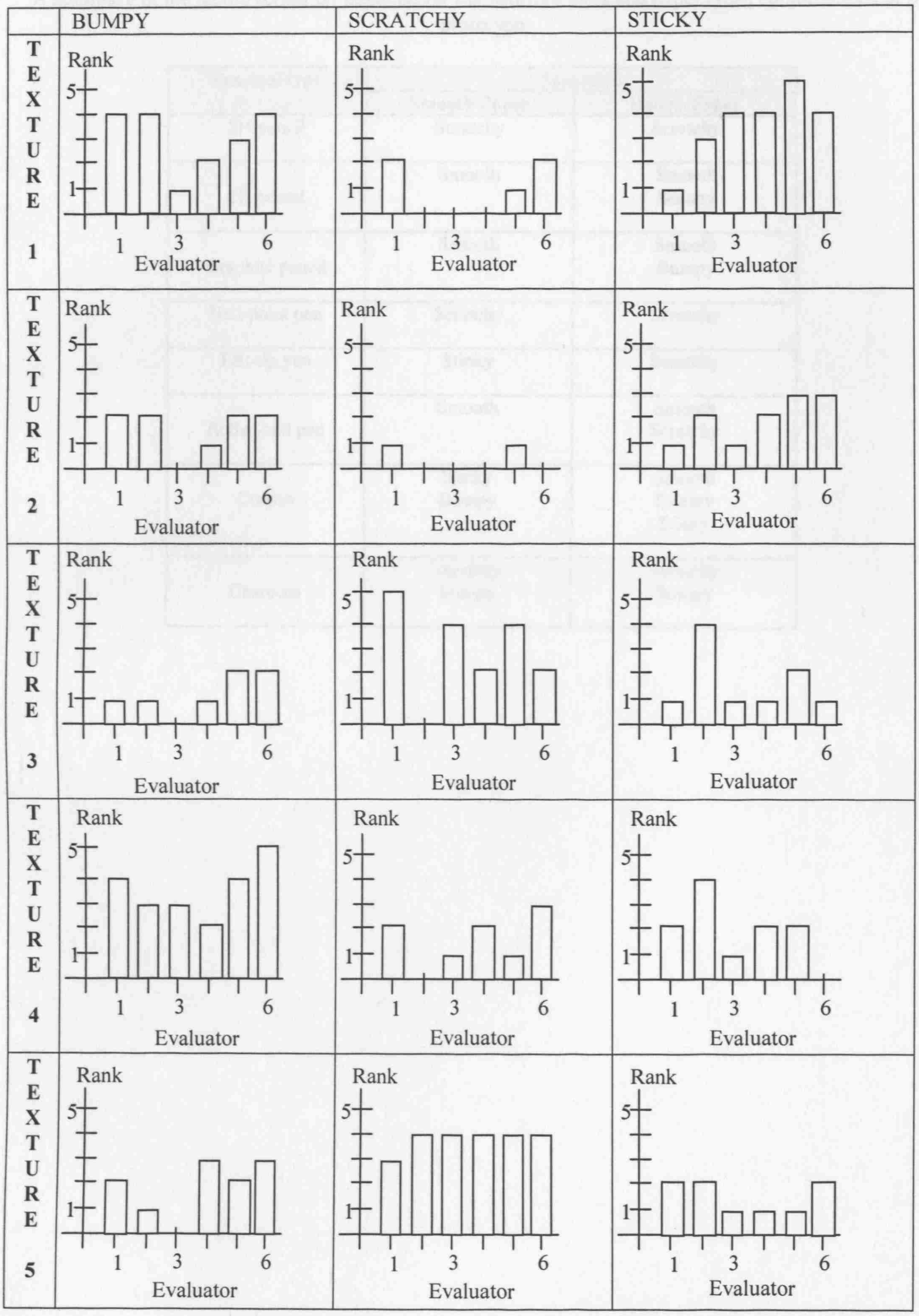
Texture 5

Bumpiness 1 2 3 4 5 Not Applicable. The interaction feels ...
Flow/ velvety *Bumpy/ coarse* ______________________

Scratchiness 1 2 3 4 5 Not Applicable. The interaction feels ...
Dry/ sharp *Scratchy/ coarse* ______________________

Stickiness 1 2 3 4 5 Not Applicable. The interaction feels ...
Flow *Sticky/ dragging* ______________________

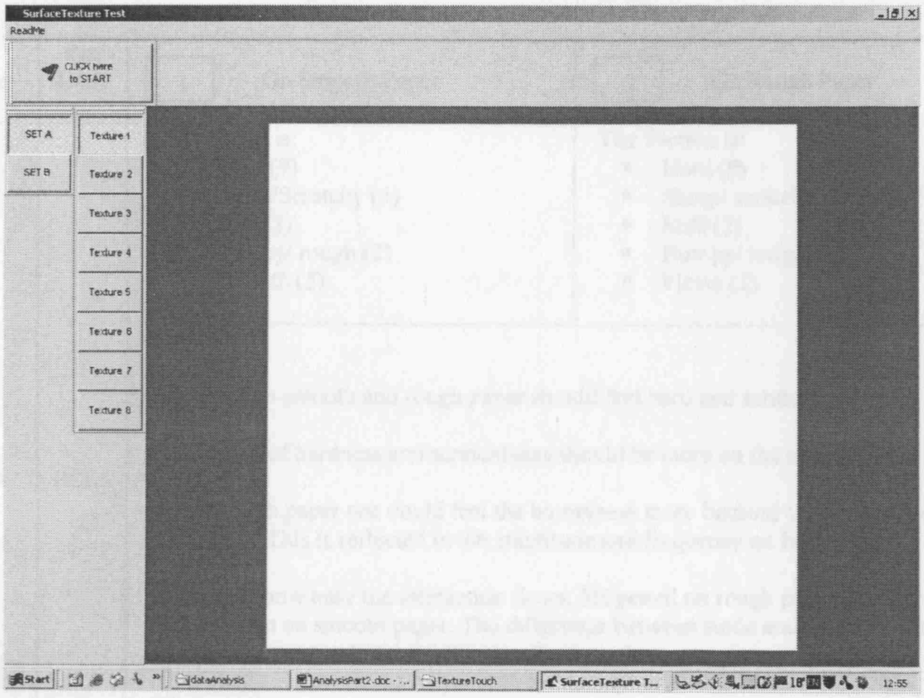
Graphical distributions of evaluators' opinions on the bumpiness, scratchiness and stickiness for the five surface textures



A summary of the tactile sensation intended for the pen-like tools and paper types combinations of the prototype

Pen-tool type	**Sensation**	
	Smooth Paper	**Rough Paper**
3H pencil	Scratchy	Scratchy
2B pencil	Smooth	Smooth Bumpy
Graphite pencil	Smooth	Smooth Bumpy
Ball-point pen	Scratchy	Scratchy
Felt-tip pen	Sticky	Scratchy
Roller-ball pen	Smooth	Smooth Scratchy
Crayon	Sticky Bumpy	Smooth Bumpy Sticky
Charcoal	Scratchy Bumpy	Scratchy Bumpy

A Sample of the Interface Design Used in the Formative Evaluation - Second Part of Test 3



Appendix 6-9

An Example of Tactile Information for a Pen-tool and Paper Type Used in the Study with the Traditional Artists Described in Chapter 3.

<table>
<tr><th>Pen Name</th><th>Pen Code</th><th>1 On Smooth Paper</th><th>2 On Rough Paper</th></tr>
<tr><td rowspan="3">3H Pencil</td><td rowspan="3">PCL5</td><td>The friction is:
▪ Hard (9)
▪ Sharp/Scratchy (4)
▪ Stiff (2)
▪ Bumpy/ rough (2)
▪ Smooth (5)</td><td>The friction is:
▪ Hard (5)
▪ Sharp/ scratchy (1)
▪ Stiff (2)
▪ Bumpy/ rough (3)
▪ Flows (1)</td></tr>
<tr><td colspan="2">Comments:

3H pencil on smooth and rough paper should feel hard and scratchy.

The feeling of hardness and scratchiness should be more on the smooth paper.

On the rough paper one could feel the bumpiness more because the pen tip is sharper and harder. This is reflected in the amplitude and frequency on both papers.

In terms of how easy the interaction flows, 3H pencil on rough paper should be more resilient than on smooth paper. The difference between static and dynamic friction on rough paper should be smaller than its smooth counterpart.

The static friction is even more on the rough paper because the sharp, hard nib gets stuck into the grooves. It flows well when the pencil is in motion. Thus, the dynamic friction is set high.</td></tr>
<tr><td>Static Friction: 0.60
Dynamic Friction: 0.45
Spring/ Stiffness: 0.65
Damping: 0.002

Amplitude – X axis: 0.15
Frequency – X axis: 800, 000

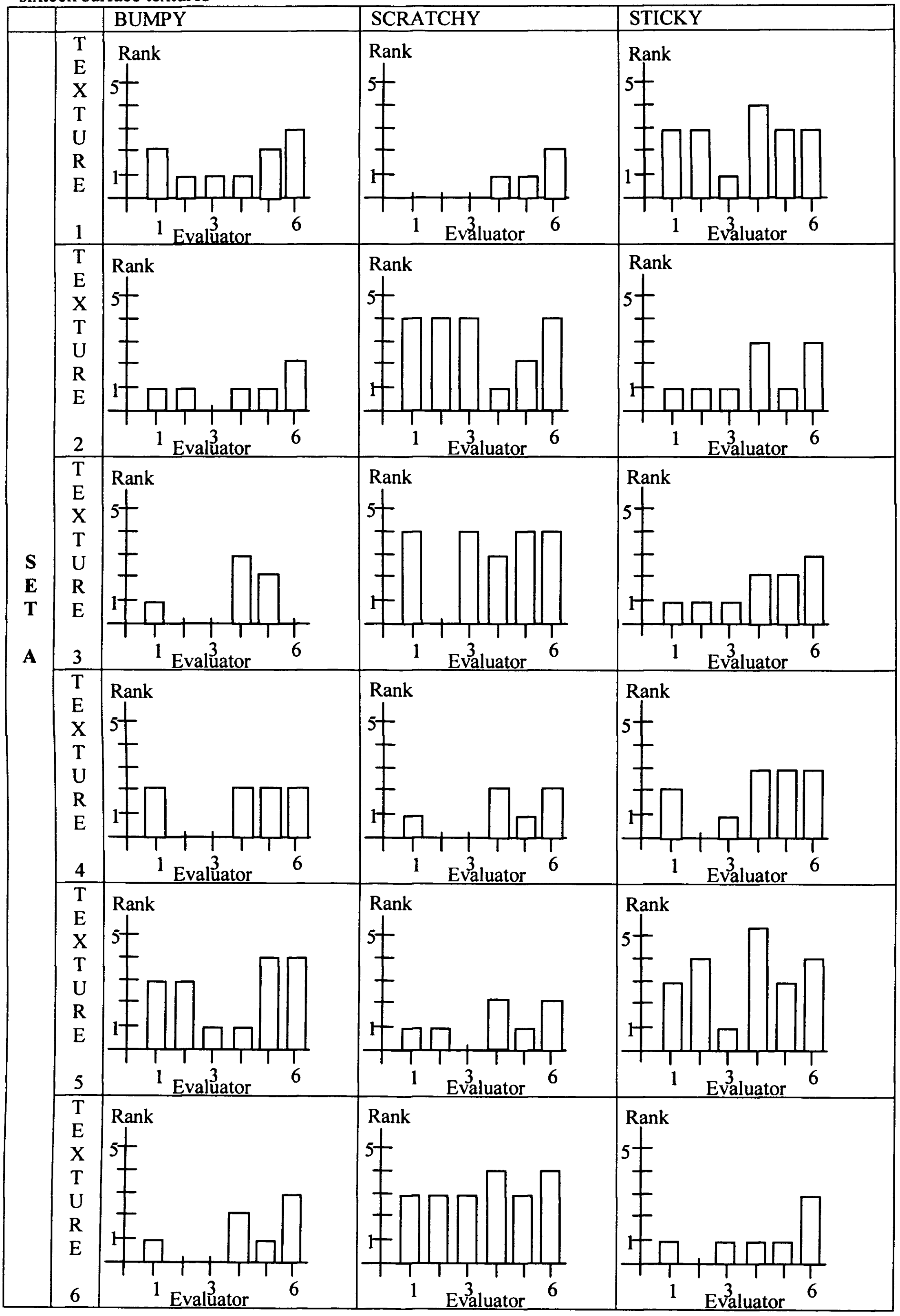
Amplitude – Y axis: 0.15
Frequency – Y axis: 700, 000</td><td>Static Friction: 0.60
Dynamic Friction: 0.50
Spring/ Stiffness: 0.60
Damping: 0.002

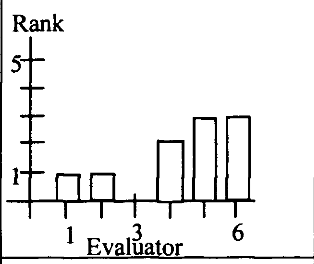
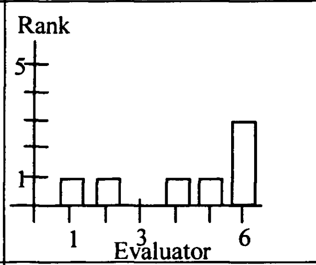
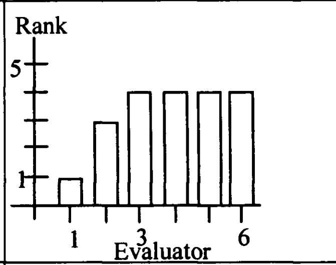
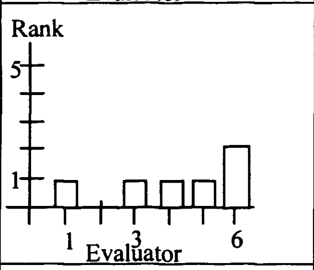
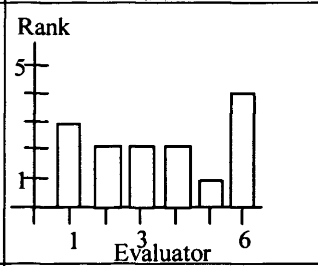
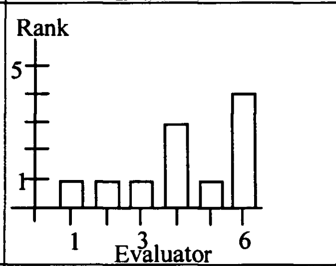
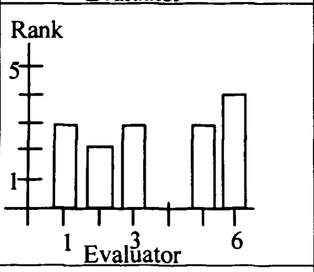
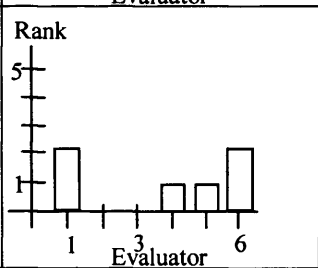
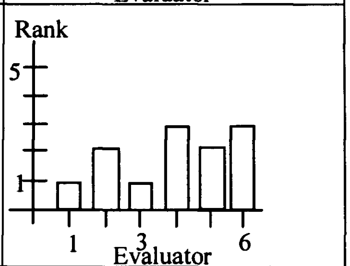
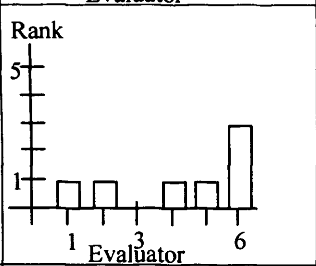
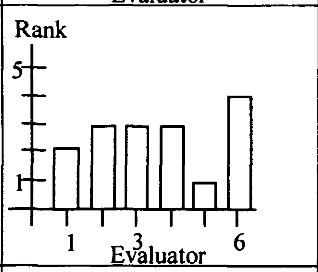
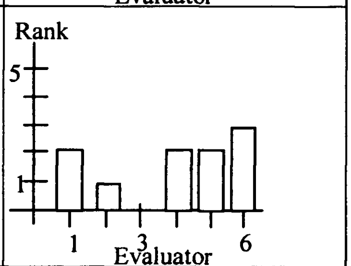
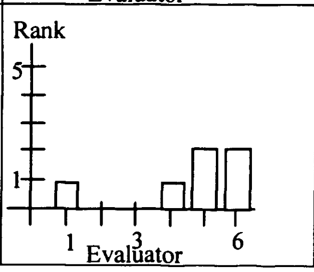
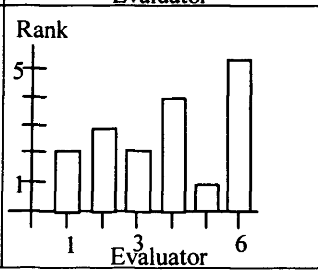
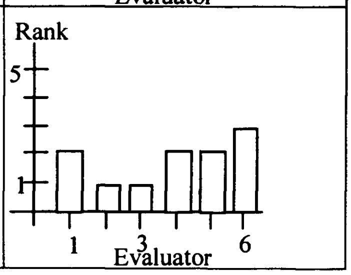
Amplitude – X axis: 0.20
Frequency – X axis: 700, 000

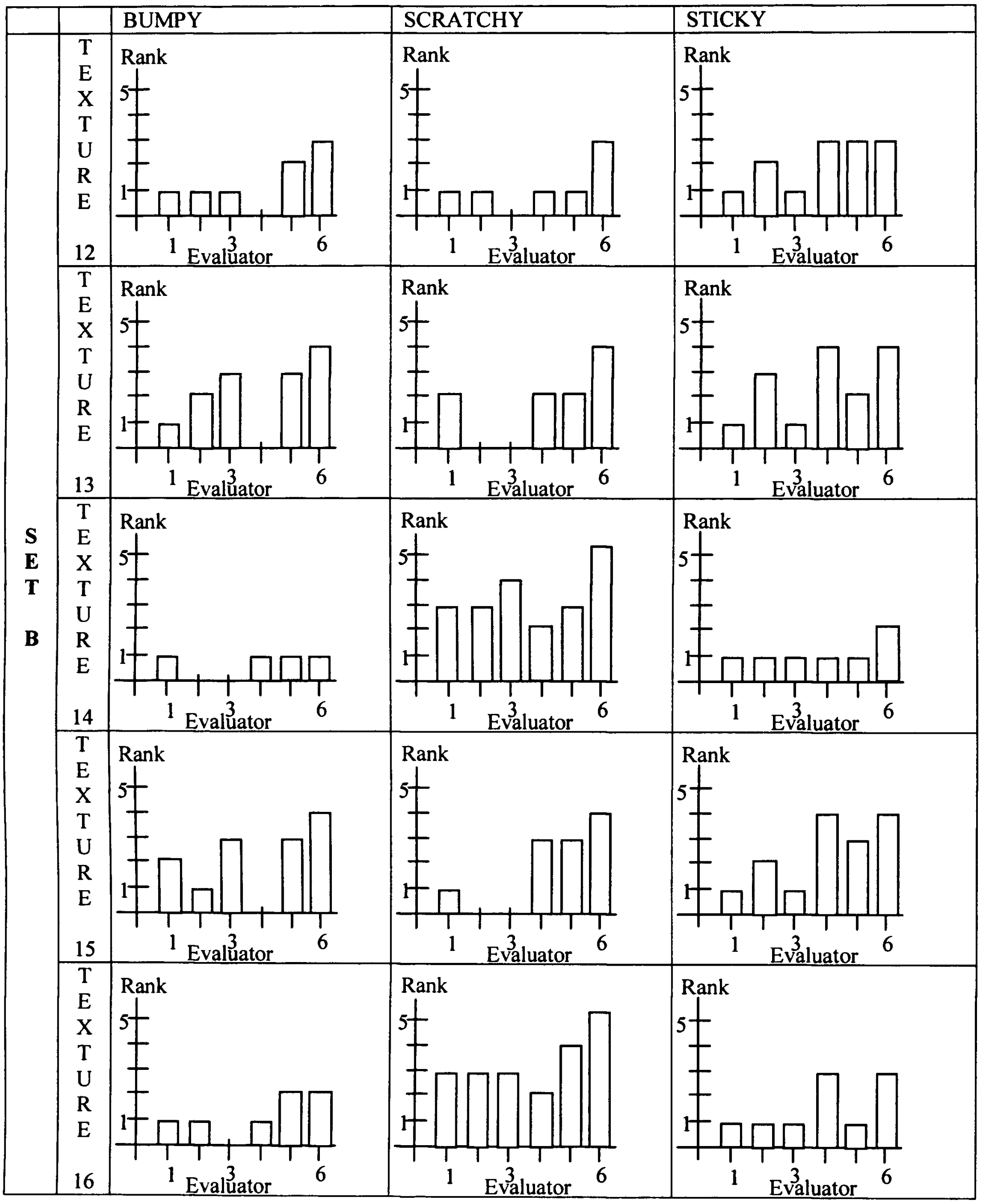
Amplitude – Y axis: 0.20
Frequency – Y axis: 700, 000</td></tr>
</table>

Parameters	Range
setSurfaceKspring	0 – 1.0
setSurfaceKdamping	0 – 0.005
setSurfaceFstatic	0 – 1.0
setSurfaceFdynamic	0 – 1.0

Graphical distributions of evaluators' opinions on the bumpiness, scratchiness and stickiness for the sixteen surface textures



		BUMPY	SCRATCHY	STICKY
SET A	TEXTURE 7			
	TEXTURE 8			
SET B	TEXTURE 9			
	TEXTURE 10			
	TEXTURE 11			


BUMPY
SCRATCHY
STICKY
SET B
TEXTURE 12
TEXTURE 13
TEXTURE 14
TEXTURE 15
TEXTURE 16
Rank
5
1
1
3
6
Evaluator

Final Datasets for Metaphor Interface Design

	Pen-tool	Friction		Stiffness	Damping	Amplitude		Frequency	
		Static	Dynamic			X-axis	Y-axis	X-axis	Y-axis
SMOOTH PAPER	3H pencil	0.60	0.45	0.65	0.002	0.15	0.15	800,000	700,000
	2B pencil	0.46	0.45	0.50	0.002	0.10	0.10	250	250
	Graphite pencil	0.40	0.40	0.450	0.003	0.10	0.10	200	200
	Ball-point pen	0.60	0.50	0.65	0.002	0.15	0.15	900,000	800,000
	Felt-tip pen	0.75	0.65	0.50	0.002	0.10	0.05	6000	3000
	Roller-ball pen	0.50	0.50	0.475	0.003	0.10	0.10	250	250
	Crayon	1.0	0.90	0.50	0.002	0.20	0.20	200	200
	Charcoal	0.50	0.46	0.620	0.002	0.20	0.20	6000	6000
ROUGH PAPER	3H pencil	0.60	0.50	0.60	0.002	0.20	0.20	700,000	700,000
	2B pencil	0.50	0.45	0.625	0.003	0.20	0.20	325	325
	Graphite pencil	0.415	0.415	0.475	0.003	0.15	0.15	250	250
	Ball-point pen	0.60	0.475	0.625	0.002	0.20	0.20	4000	2000
	Felt-tip pen	0.50	0.475	0.60	0.002	0.20	0.20	4000	2000
	Roller-ball pen	0.525	0.50	0.615	0.003	0.20	0.20	350	350
	Crayon	0.90	0.80	0.50	0.002	0.20	0.20	375	375
	Charcoal	0.50	0.470	0.610	0.002	0.20	0.20	3000	1000

Table 3: Datasets for Interface 3 (User-Controlled Interface)

3. Low bumpy = the amplitude of graphite pencil on smooth paper

Bumpy	Sticky	Scratchy	Friction		Stiffness	Damping	Amplitude		Frequency	
			Static	Dynamic			X-axis	Y-axis	X-axis	Y-axis
Low	Low	Low	0.40	0.40	0.50	0.002	0.10	0.10	200	200
		Med	0.40	0.40	0.50	0.002	0.10	0.10	4000	2000
		High	0.40	0.40	0.50	0.002	0.10	0.10	900,000	800,000
	Med	Low	0.75	0.65	0.50	0.002	0.10	0.10	200	200
		Med	0.75	0.65	0.50	0.002	0.10	0.10	4000	2000
		High	0.75	0.65	0.50	0.002	0.10	0.10	900,000	800,000
	High	Low	1.0	0.90	0.50	0.002	0.10	0.10	200	200
		Med	1.0	0.90	0.50	0.002	0.10	0.10	4000	2000
		High	1.0	0.90	0.50	0.002	0.10	0.10	900,000	800,000
High	Low	Low	0.40	0.40	0.50	0.002	0.20	0.20	200	200
		Med	0.40	0.40	0.50	0.002	0.20	0.20	4000	2000
		High	0.40	0.40	0.50	0.002	0.20	0.20	900,000	800,000
	Med	Low	0.75	0.65	0.50	0.002	0.20	0.20	200	200
		Med	0.75	0.65	0.50	0.002	0.20	0.20	4000	2000
		High	0.75	0.65	0.50	0.002	0.20	0.20	900,000	800,000
	High	Low	1.0	0.90	0.50	0.002	0.20	0.20	200	200
		Med	1.0	0.90	0.50	0.002	0.20	0.20	4000	2000
		High	1.0	0.90	0.50	0.002	0.20	0.20	900,000	800,000

4. High sticky = the friction of crayon on smooth paper

1. Constant (see Interface 1)

2. High bumpy = the amplitude of crayon on rough paper

6. Med sticky = the friction of felt-tip on smooth paper

7. High scratchy = the freq of ballpoint pen on smooth paper

5. Low sticky = the friction of graphite pencil on smooth paper

9. Med scratchy = the freq of ballpoint on rough paper

8. Low scratchy = the freq of graphite pencil on smooth paper

Instructions for the Evaluators

4th October 2005

HapticDraw Prototype Evaluation Study: General Information

Thank you for volunteering to participate in this study. This is one in a series of studies aimed at evaluating a prototype called HapticDraw.

The aim of this study is to understand the tactile experience of using several interfaces to the HapticDraw prototype for drawing and sketching. You will be given adequate training to get yourself familiar interacting with the interface before performing the actual study. In this study you will use a haptic device called Phantom to draw on the interface and a mouse to change the menu options. This study is not to test your ability to use the devices nor to assess your drawings but rather, to evaluate the prototype itself.

The whole study takes about 60 minutes. Please say out loud your experience when interacting with the interfaces during the study.

Please be informed that the conversation in this study will be recorded. We can assure you that the recorded information will be strictly used for the purpose of this study only and will be kept in such a way that you cannot be identified from the data.

Please feel free to ask questions pertaining to this study. While the researcher will be happy to answer any general questions you may have, s/he has been instructed not to discuss some aspects of the study until the end.

You will be given a Consent Form pertaining to this study very shortly. Please read and sign the form.

Thank you.

University College London
Remax House, 31-32 Alfred Place
London WC1E 7DP
United Kingdom

Tel: <02076795225> email: <s.sulaiman@ucl.ac.uk>

Identification Number for this trial: ___

CONSENT FORM

Title of Study: HapticDraw Prototype Evaluation Study

Please tick box

4. I confirm that I have read and understood the general information sheet for the above study and have had the opportunity to ask questions. ☐

5. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason, without my legal rights being affected. ☐

3. I agree to take part in the above study. ☐

____________________	____________________	____________________
Interviewee name	Date	Signature
____________________	____________________	____________________
Researcher	Date	Signature

Task Set A (Object-based Metaphor Interface – Fixed Sensation)

The objective of this interface is to determine if haptic cues are important in a drawing application. The findings from this exercise will be compared with both Interface 2 and 3. An example of the variable haptic interface is presented in Figure 1.

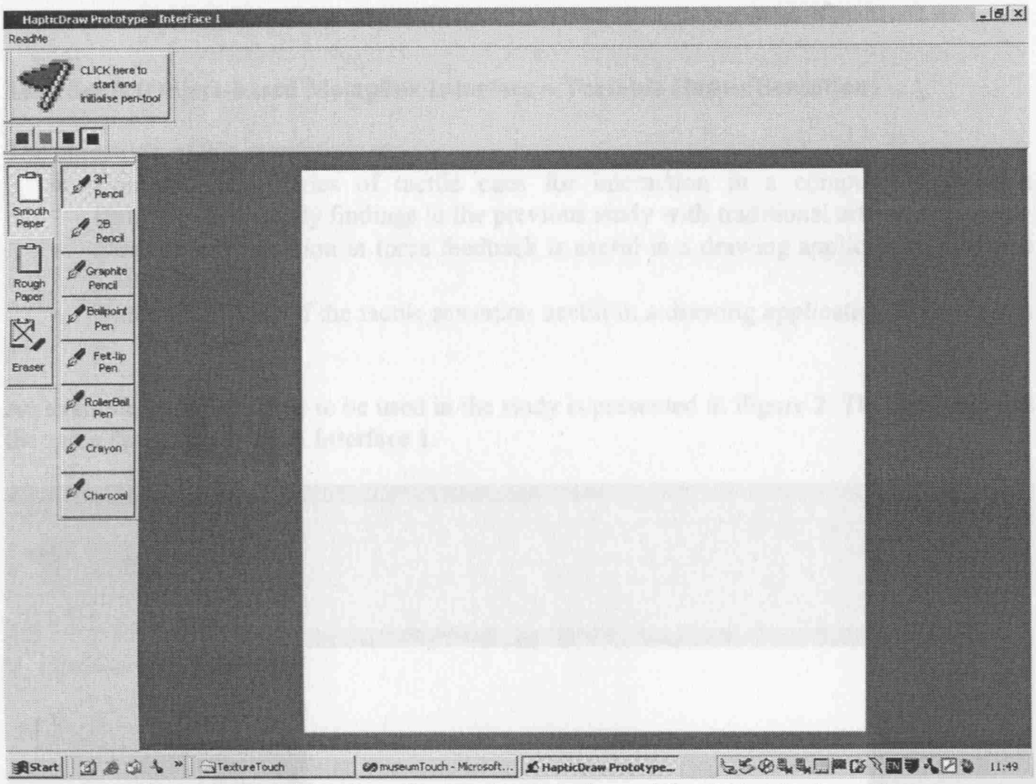


Figure 1: An Object-based metaphor Interface – Fixed Haptic Sensation

The participants will be given about 5 minutes to interact using Interface 1. Like in the training session, the participants have to make some free drawings or sketches on the interface. They have to try each pen-tool and paper-type combination and say out loud the tactile sensation felt during the interaction. (The experimenter/ researcher will determine the sequence of the pen-tool and paper type combinations so that a random selection can be maintained). The think aloud exercise is important because the evaluators' feedback will be used in some part of the questions during the debriefing session.

The series of questions to be asked from the participants during debriefing depend on the sequence of the task set performed by the participants. For example,

If Task Set A is performed **before** B or C the question to be asked will be as follows:

1. During your interaction using Interface 1 you mentioned that the tactile sensation is ______ (e.g. slippery, frictionless etc). What is your overall comment on the tactile interaction in this exercise? (i.e. your preference whether you like this ______ (e.g. slipperiness) feeling or not)

If Task Set A is performed **after** either Task Set B or C an additional question that will be asked is:

2. In terms of the tactile sensation, which of the two interfaces i.e. (Interface 1 or Interface 2/ 3) you prefer to have when drawing or sketching? Why?

Task Set B (Object-based Metaphor Interface – Variable Haptic Sensation)

The objectives of this interface is to:

- Compile vocabularies of tactile cues for interaction in a computer application (Interface 2 vs. study findings in the previous study with traditional artists)
- Determine if variation in force feedback is useful in a drawing application (Interface 1 vs. Interface 2)
- Determine which of the tactile sensation useful in a drawing application and why it is so

An example of the interface to be used in the study is presented in Figure 2. This interface has the same design layout with Interface 1.

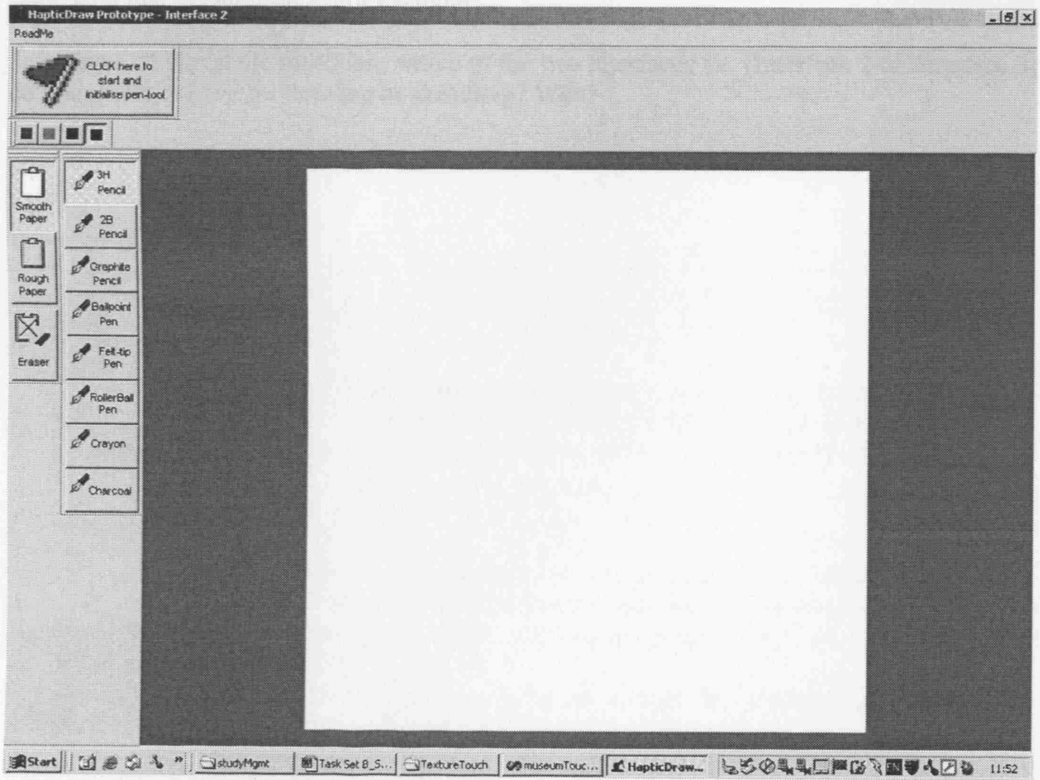


Figure 2: An Object-based Metaphor Interface – Variable Haptic Sensation

The participants will be given about 10 to 15 minutes to interact using Interface 2. They have to make some free drawings or sketches on the interface. They have to try each pen-tool and paper-type combination and say out loud the tactile sensation felt during the interaction. (The experimenter/ researcher will determine the sequence of the pen-tool and paper type combinations so that a random selection can be maintained). The think aloud exercise is very important because the vocabularies used will be compared to those compiled in the earlier study. The participants will also be asked to take note on the pen-tool and paper type combinations they prefer to use in a drawing application.

During the debriefing, the questions to be asked from the participants depend on the sequence of the task set performed by the participants. For example,

If Task Set B is performed **before** A or C the question asked will be as follows:

1. In terms of the tactile sensation, which of the pen-tool and paper type combinations do you prefer to use? And why?

If Task Set B is performed **after** Task Set A the additional question to be asked is:

2. In terms of the tactile sensation, which of the two interfaces i.e. (Interface 1 or Interface 2) do you prefer to have for drawing or sketching? Why?

If Task Set B is performed **after** Task Set C the additional question to be asked is about the same with that in Question 2. For example:

3. In terms of the tactile sensation, which of the two interfaces i.e. (Interface 2 or Interface 3) do you prefer to have for drawing or sketching? Why?

Task Set C (A Textual Description Metaphor Interface - Variable Haptic Sensation)

The objectives of this interface is to:

- Determine if variation in force feedback is useful in a drawing application (Interface 1 vs. Interface 3)
- Determine which of the two representations of the haptic cues information users prefer to have and the reason for it (Interface 2 vs. Interface 3)

An example of the interface to be used in the study is presented in Figure 3.

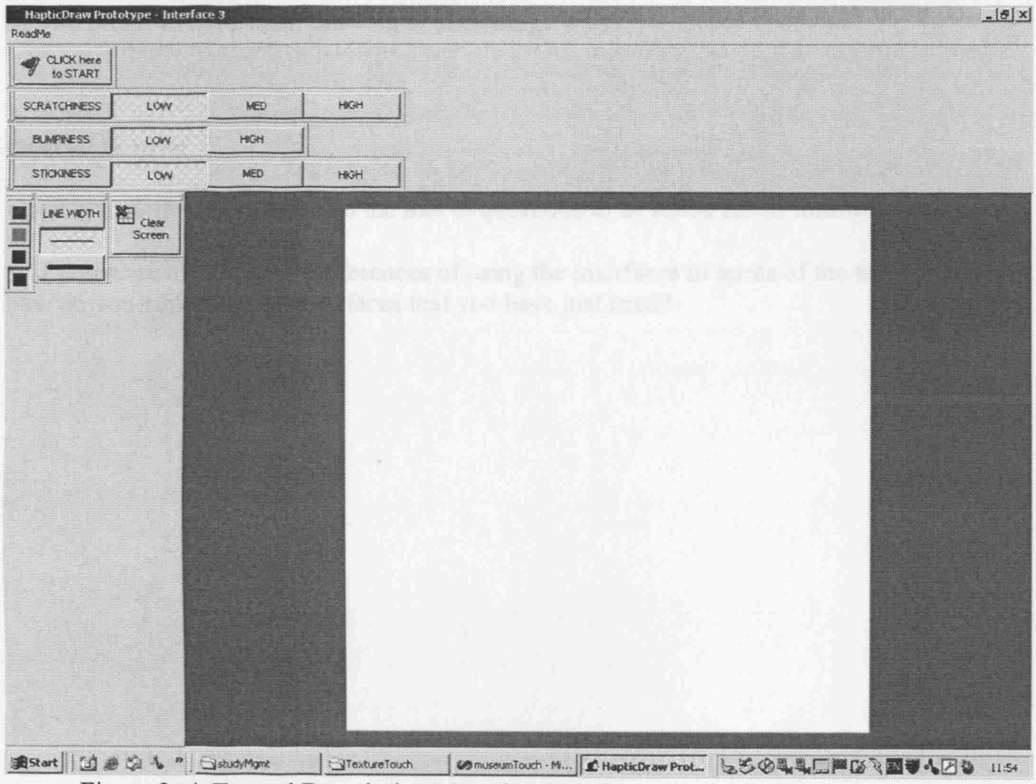


Figure 3: A Textual Description Metaphor Interface – Variable Haptic Sensation

Like interacting using Interface 2, the participants will be given about 10 to 15 minutes to make some free drawings or sketches on Interface 3. They will be asked to take note on the combination of tactile cues they prefer to use in a drawing application.

During the debriefing session, the questions to be asked from the participants depend on the sequence of the task set performed by the participants. For example:

If Task Set C is performed first i.e. **before** A or B the question asked will be as follows:

1. In terms of the tactile sensation, which of the cue combinations do you like best? And why?

If Task Set C is performed **after** Task Set A, the additional question to be asked is:

2. In terms of the tactile sensation, which of the two interfaces i.e. (Interface 1 or Interface 2) do you prefer to have when drawing or sketching? Why?

If Task Set C is performed **after** Task Set B the additional question to be asked is:

3. In terms of the tactile sensation, which of the two interfaces i.e. (Interface 2 or Interface 3) do you prefer to have when drawing or sketching? Why?

Overall Debrief

Upon completion of all task sets the sort of questions to be asked are as follows:

1. If you were to rank your preferences of using the interfaces in terms of the tactile sensation, how do you rank the three interfaces that you have just tried?

Ranking the Interface

Evaluator __________

E.g.

Few Haptic Choices		Many Haptic Choices
1		2 3

Great Fun	Not Fun

Not Emotionally Fulfilling	Very Emotionally Fulfilling

Not Rewarding	Very Rewarding

Very Supportive of Creativity	Not Supportive of Creativity

Not Aesthetically Pleasing	Very Aesthetically Pleasing

Very Motivating	Not Motivating

Not Helpful	Very Helpful

Not Entertaining	Very Entertaining

Not Enjoyable	Very Enjoyable

Very Satisfying	Not Satisfying

Ranking of Interfaces Based on Individual Artist

Artist: 1			
User Experience Goal	Preference		
	Least ==> Most		
Fun	1	2	3
Emotionally Fulfilling	1	2	& 3
Rewarding	1 &	2	& 3
Supportive of Creativity	1	2	& 3
Aesthetically Pleasing	1 &	2	& 3
Motivating	1	2	3
Helpful	1 &	2	& 3
Entertaining	1	2	& 3
Enjoyable	1	2	& 3
Satisfying	1 &	2	3

Interface 3 => 3
Interface 2&3 => 4
Interface 1&2&3 => 3

Artist: 2			
User Experience Goal	Preference		
	Least ==> Most		
Fun	1	3	2
Emotionally Fulfilling	1	3	2
Rewarding	1	3	2
Supportive of Creativity	1	2	3
Aesthetically Pleasing	1	3	2
Motivating	3	1	2
Helpful	3	1	2
Entertaining	1	3	2
Enjoyable	1	3	2
Satisfying	1	3	2

Interface 2 => 9
Interface 3 => 1

Artist: 3			
User Experience Goal	Preference		
	Least ==> Most		
Fun	2	1	3
Emotionally Fulfilling	1	2	3
Rewarding	1 &	2	& 3
Supportive of Creativity	2	1	3
Aesthetically Pleasing	3	2	1
Motivating	1 &	2	& 3
Helpful	1 &	2	& 3
Entertaining	1 &	2	& 3
Enjoyable	1 &	2	& 3
Satisfying	2 &	3	1

Interface 1 => 2
Interface 3 => 3
Interface 1&2&3 => 5

Artist: 4			
User Experience Goal	Preference		
	Least ==> Most		
Fun	1	2	& 3
Emotionally Fulfilling	1	2	3
Rewarding	1 &	2	& 3
Supportive of Creativity	1 &	2	& 3
Aesthetically Pleasing	1 &	2	& 3
Motivating	1 &	2	& 3
Helpful	1 &	2	& 3
Entertaining	1	2	3
Enjoyable	1	2	3
Satisfying	1	2	& 3

Interface 3 => 3
Interface 1&2&3 => 5
Interface 2&3 => 2

Artist: 5			
User Experience Goal	Preference		
	Least ==> Most		
Fun	1	2	3
Emotionally Fulfilling	1	3	2
Rewarding	1	3	2
Supportive of Creativity	1	2	3
Aesthetically Pleasing	1	2	3
Motivating	1	2	3
Helpful	1	3	2
Entertaining	1	3	2
Enjoyable	1	3	2
Satisfying	1	3	2

Interface 2 => 6
Interface 3 => 4

Artist: 6			
User Experience Goal	Preference		
	Least ==> Most		
Fun	2	1	3
Emotionally Fulfilling	2	1	3
Rewarding	1	2	3
Supportive of Creativity	2	1	3
Aesthetically Pleasing	1	2	3
Motivating	2	1	3
Helpful	1	2	3
Entertaining	1	2	3
Enjoyable	2	1	3
Satisfying	1	2	3

Interface 3 => 10

Artist: 7			
User Experience Goal	Preference		
	Least ==> Most		
Fun	1	2	3
Emotionally Fulfilling	1	2	3
Rewarding			
Supportive of Creativity	1	2	3
Aesthetically Pleasing	1	2	3
Motivating	1	2	3
Helpful	1	3	2
Entertaining	1	2	3
Enjoyable	1	2	3
Satisfying	1	2	3

Interface 3 => 8
Interface 2 => 1
N/A => 1

Artist: 8			
User Experience Goal	Preference		
	Least ==> Most		
Fun	1	3	2
Emotionally Fulfilling	2	3	1
Rewarding	2	3	1
Supportive of Creativity	1	3	2
Aesthetically Pleasing	2 &	3	1
Motivating	1	3	2
Helpful	2	3	1
Entertaining	2	3	1
Enjoyable	2	3	1
Satisfying	1	3	2

Interface 2 => 4
Interface 1 => 6

Artist: 9			
User Experience Goal	Preference		
	Least ==> Most		
Fun	2	3	1
Emotionally Fulfilling	1	2	3
Rewarding	1	2	3
Supportive of Creativity	1	2	3
Aesthetically Pleasing	1	2	3
Motivating	1	2	3
Helpful	1	2	3
Entertaining	1	3	2
Enjoyable	1	3	2
Satisfying	1	2	3

Interface 3 => 7
Interface 1 => 1
Interface 2 => 2

Artist: 10			
User Experience Goal	Preference		
	Least ==> Most		
Fun	1	3	2
Emotionally Fulfilling	1	3	2
Rewarding	1	3	2
Supportive of Creativity	2	3	1
Aesthetically Pleasing	1	3	2
Motivating	1	3	2
Helpful	1	3	2
Entertaining	1	3	2
Enjoyable	1	3	2
Satisfying	1	3	2

Interface 2 => 9
Interface 1 => 1

Artist: 11			
User Experience Goal	Preference		
	Least ==> Most		
Fun	1	2	3
Emotionally Fulfilling	1	2	3
Rewarding	1	3	2
Supportive of Creativity	1	2	3
Aesthetically Pleasing	1	2	3
Motivating	1	3	2
Helpful	3	1	2
Entertaining	1	2	3
Enjoyable	1	2	3
Satisfying	1	3	2

Interface 2 => 4
Interface 3 => 6

Artist: 12			
User Experience Goal	Preference		
	Least ==> Most		
Fun	1	2	3
Emotionally Fulfilling	1	2	3
Rewarding	2	3	1
Supportive of Creativity	1	2	3
Aesthetically Pleasing	1	3	2
Motivating	1	2	3
Helpful	1	2	3
Entertaining	1	2	3
Enjoyable	1	2	3
Satisfying	1	3	2

Interface 3 => 7
Interface 2 => 2
Interface 1 => 1

Artist: 13			
User Experience Goal	Preference		
	Least ==> Most		
Fun	1	2	3
Emotionally Fulfilling	1	2	3
Rewarding	1	2	3
Supportive of Creativity	3	2	1
Aesthetically Pleasing	1	2	3
Motivating	1	2	3
Helpful	1	2	3
Entertaining	1	2	3
Enjoyable	1	2	3
Satisfying	1	2	3

Interface 3 => 9
Interface 1 => 1

Artist: 14			
User Experience Goal	Preference		
	Least ==> Most		
Fun	1		2
Emotionally Fulfilling	3	2	1
Rewarding	2	3	1
Supportive of Creativity	2	3	1
Aesthetically Pleasing	3	2	1
Motivating	3	2	1
Helpful	2	3	1
Entertaining	3	2	1
Enjoyable	3	1	2
Satisfying	3	2	1

Interface 1 => 8
Interface 2 => 2

Artist: 15			
User Experience Goal	Preference		
	Least ==> Most		
Fun	1 &	2	& 3
Emotionally Fulfilling	1 &	3	2
Rewarding	3	1	& 2
Supportive of Creativity	1 &	2	3
Aesthetically Pleasing	1 &	2	& 3
Motivating	1	3	2
Helpful	1 &	2	& 3
Entertaining	1 &	2	& 3
Enjoyable	1 &	2	& 3
Satisfying	2	1	3

Interface 2 => 2
Interface 3 => 2
Interface 1&2&3 => 5
Interface 1&2 => 1

Artist: 16			
User Experience Goal	Preference		
	Least ==> Most		
Fun	1	2	3
Emotionally Fulfilling	1 &	2	3
Rewarding	1	2	3
Supportive of Creativity	2	1	3
Aesthetically Pleasing	2 &	3	1
Motivating	1 &	2	3
Helpful	1 &	2	& 3
Entertaining	1	2	3
Enjoyable	1	2	3
Satisfying	1 &	2	& 3

Interface 3 => 7
Interface 1&2&3 => 2
Interface 1 => 1

Artist: 17			
User Experience Goal	Preference		
	Least ==> Most		
Fun	1	2	3
Emotionally Fulfilling	1	3	2
Rewarding	1	3	2
Supportive of Creativity	1	3	2
Aesthetically Pleasing	1	3	2
Motivating	1	3	2
Helpful	1	3	2
Entertaining	1	2	3
Enjoyable	1	3	2
Satisfying	1	3	2

Interface 2 => 8
Interface 3 => 2

Artist: 18			
User Experience Goal	Preference		
	Least ==> Most		
Fun	1	3	2
Emotionally Fulfilling	1	3	2
Rewarding	1	3	2
Supportive of Creativity	2	3	1
Aesthetically Pleasing	3	1	2
Motivating	2	1	3
Helpful	3	1	2
Entertaining	3	1	2
Enjoyable	3	1	2
Satisfying	1	3	2

Interface 2 => 8
Interface 1 => 1
Interface 3 => 1

Artist: 19			
User Experience Goal	Preference		
	Least ==> Most		
Fun	2	1	3
Emotionally Fulfilling	2	1	3
Rewarding	2	1	3
Supportive of Creativity	2	1	3
Aesthetically Pleasing	2	1	3
Motivating	2	1	3
Helpful	2	1	3
Entertaining	2	1	3
Enjoyable	2	1	3
Satisfying	2	1	3

Interface 3 => 10

Artist: 20			
User Experience Goal	Preference		
	Least ==> Most		
Fun	3	2	1
Emotionally Fulfilling	1	2	3
Rewarding	1	3	2
Supportive of Creativity	2	1	3
Aesthetically Pleasing	1	3	2
Motivating	2	3	1
Helpful	2	3	1
Entertaining	1	2	3
Enjoyable	1	2	3
Satisfying	1	3	2

Interface 1 => 3
Interface 2 => 3
Interface 3 => 4

Artist: 21			
User Experience Goal	Preference		
	Least ==> Most		
Fun	3	1	2
Emotionally Fulfilling	3	1	2
Rewarding	3	1	2
Supportive of Creativity	3	1	2
Aesthetically Pleasing	1	3	2
Motivating	3	1	2
Helpful	3	1	2
Entertaining	3	1	2
Enjoyable	3	1	2
Satisfying	3	1	2

Interface 2 => 10

Artist: 22			
User Experience Goal	Preference		
	Least ==> Most		
Fun	1	2	3
Emotionally Fulfilling			
Rewarding	2	1	3
Supportive of Creativity	1	2	3
Aesthetically Pleasing	3	2	1
Motivating			
Helpful			
Entertaining			
Enjoyable	2	1	3
Satisfying	1	2	3

Interface 3 = 5
Interface 1 = 1
N/A => 4

Artist: 23			
User Experience Goal	Preference		
	Least ==> Most		
Fun	1	3	2
Emotionally Fulfilling	1	3	2
Rewarding	1	3	2
Supportive of Creativity	1	3	2
Aesthetically Pleasing	1	3	2
Motivating	1	3	2
Helpful	1	3	2
Entertaining	1	3	2
Enjoyable	1	3	2
Satisfying	1	3	2

Interface 2 => 10

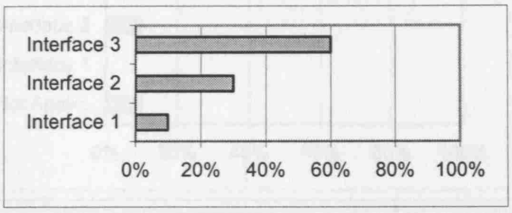
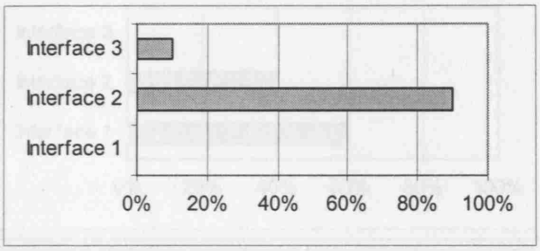
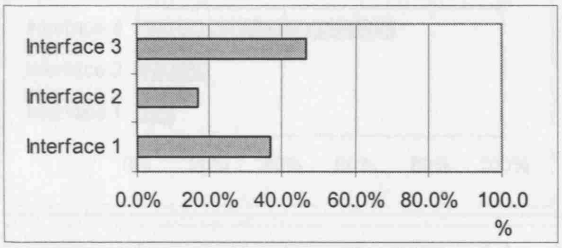
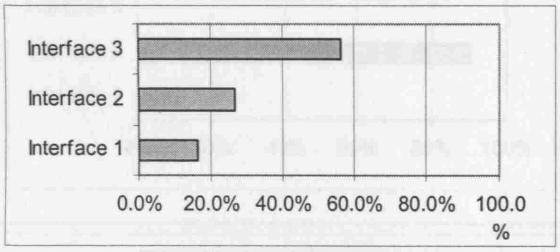
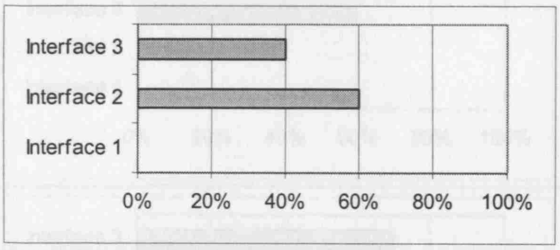
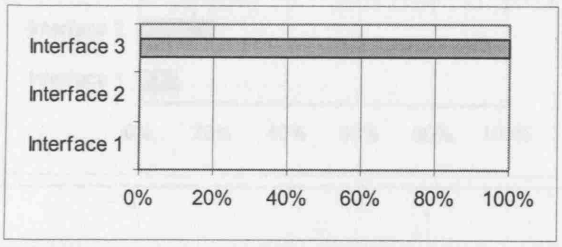
Artist: 24			
User Experience Goal	Preference		
	Least ==> Most		
Fun	1	3	2
Emotionally Fulfilling	1	3	2
Rewarding	1	2	3
Supportive of Creativity	1	3	2
Aesthetically Pleasing	1	3	2
Motivating	1	3	2
Helpful	1	3	2
Entertaining	3	1	2
Enjoyable	3	1	2
Satisfying	3	2	1

Interface 2 => 8
Interface 3 => 1
Interface 1 => 1

Percentages of Preference for Individual Interface

	INTERFACE 1	INTERFACE 2	INTERFACE 3	NOT APPLIC.
Artist 1	10%	30%	60%	
Artist 2	0%	90%	10%	
Artist 3	36.6%	16.6%	46.6%	
Artist 4	16.6%	26.6%	56.6%	
Artist 5	0%	60%	40%	
Artist 6	0%	0%	100%	
Artist 7	0%	10%	80%	10%
Artist 8	60%	40%	0%	
Artist 9	10%	20%	70%	
Artist 10	10%	90%	0%	
Artist 11	0%	40%	60%	
Artist 12	10%	20%	70%	
Artist 13	10%	0%	90%	
Artist 14	80%	20%	0%	
Artist 15	21.6%	41.6%	36.6%	
Artist 16	16.6%	6.6%	76%	
Artist 17	0%	80%	20%	
Artist 18	10%	80%	10%	
Artist 19	0%	0%	100%	
Artist 20	30%	30%	40%	
Artist 21	0%	100%	0%	
Artist 22	10%	0%	50%	40%
Artist 23	0%	100%	0%	
Artist 24	10%	80%	10%	

Bar Graph to Check Consistency of Artists' Preferences on the Interfaces

<table>
<tr><th>Artist No.</th><th>Inferred Final Preference</th><th>Preference for each individual interface with respect to the ten user experience goal criteria</th><th>Consistency Checklist
[√ => Consistent; X => NOT consistent]</th></tr>
<tr><td>1</td><td>3</td><td></td><td>√</td></tr>
<tr><td>2</td><td>2</td><td></td><td>√</td></tr>
<tr><td>3</td><td>1</td><td></td><td>X</td></tr>
<tr><td>4</td><td>3</td><td></td><td>√</td></tr>
<tr><td>5</td><td>2</td><td></td><td>√</td></tr>
<tr><td>6</td><td>3</td><td></td><td>√</td></tr>
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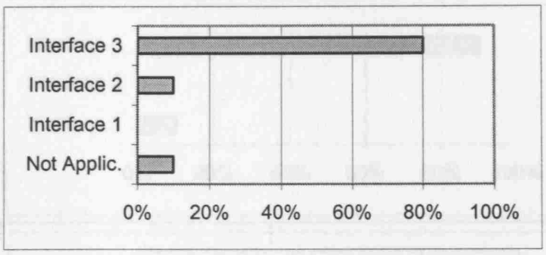
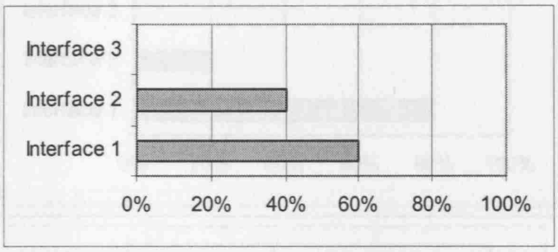
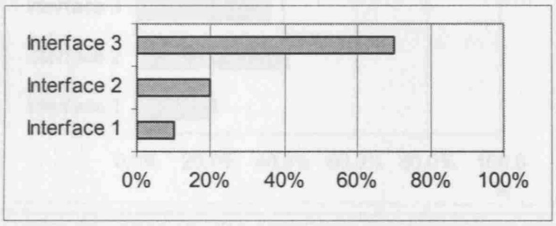
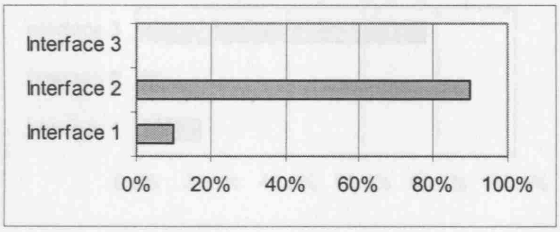
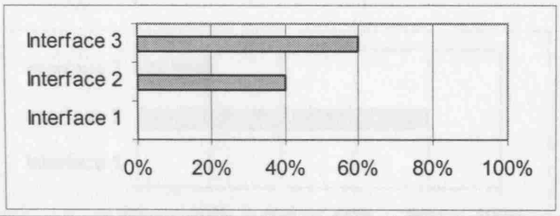
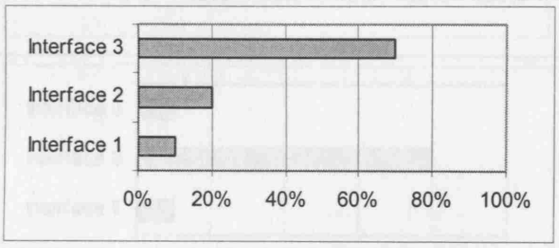
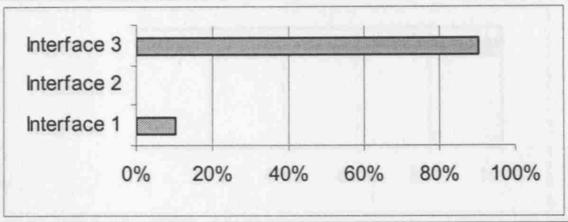
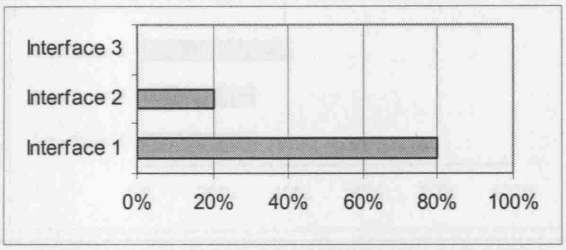
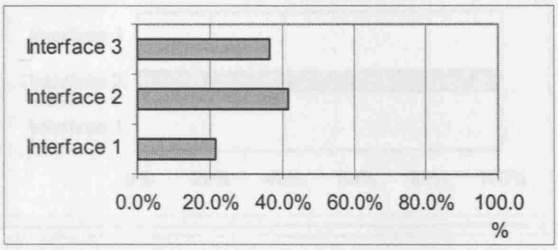
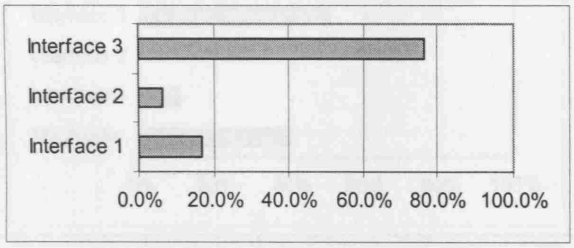
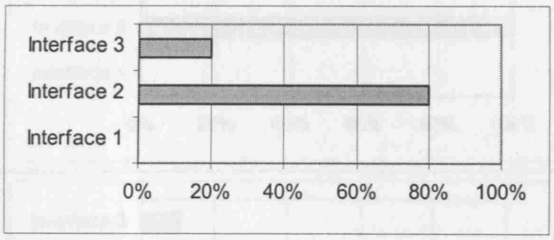
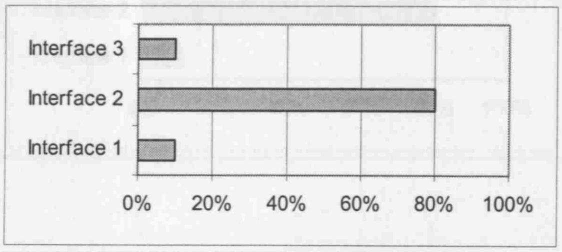
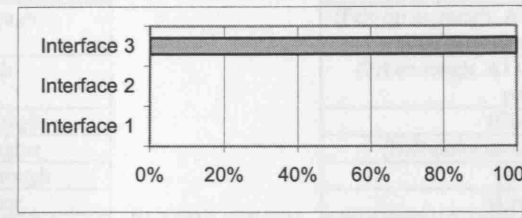
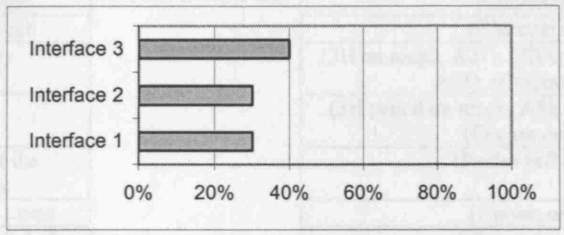
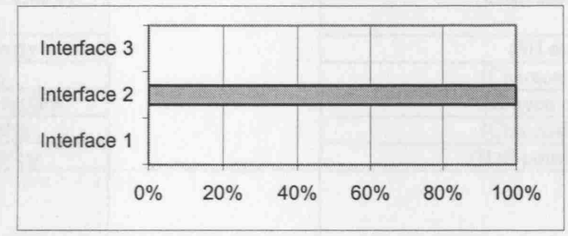
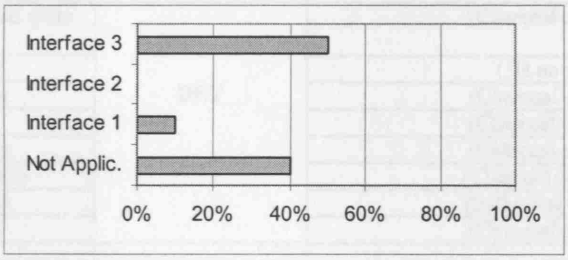
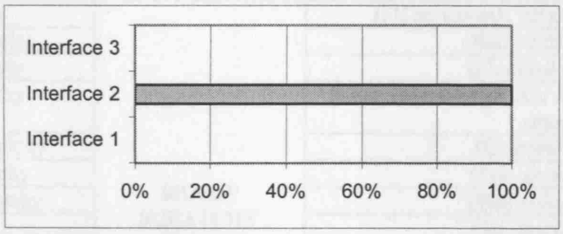
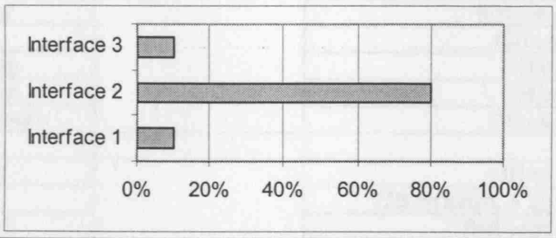
Artist No.	Inferred Final Preference	Preference for each individual interface with respect to the ten user experience goal criteria	Consistency Checklist [√ => Consistent; X => NOT consistent]
7	2&3		√
8	2		X
9	3		√
10	2		√
11	2&3		√
12	3		√

Artist No.	Inferred Final Preference	Preference for each individual interface with respect to the ten user experience goal criteria	Consistency Checklist [√ => Consistent; X => NOT consistent]
13	3		√
14	1&2		√
15	2		√
16	3		√
17	2		√
18	1		X

Artist No.	Inferred Final Preference	Preference for each individual interface with respect to the ten user experience goal criteria	Consistency Checklist [√ => Consistent; X => NOT consistent]
19	3		√
20	1&3		√
21	2		√
22	3		√
23	2		√
24	2&3		√

Features of Tactile Perception in Drawing Interaction Using Interface 2

Features	'Derived Group'	Justification
Very rough	BUMPY/ ROUGH	(Ball-point on smooth, A1); (2B on rough, A 2)
Quite rough		(Felt-tip on rough, A2); (Roller-ball on smooth, A2); (Ball-point on rough, A5); (Felt-tip on rough, A10)
Rough		(2B on rough, A13); (Charcoal on smooth, A2); (Ball-point on rough, A13)
Really rough		(Charcoal on rough, A2)
A bit rougher		(Ball-point on smooth, A5); (3H on rough, A19)
A bit too rough		(Crayon on rough, A8)
Rougher		(Crayon on rough, A22)
Not too rough		(Crayon on rough, A5)
Harsh and rough		(Charcoal on rough, A2)
Too bumpy		(3H on rough, A21); (2B on smooth, A21); (2B on rough, A21); (Crayon on smooth, A21)
Bumpy		(3H pencil on rough, A9); (Crayon on rough, A9, A22); (Crayon on smooth, A23)
A bit more of the bumpiness		(Roller-ball on rough, A23)
Feel the bump...ness		(Crayon on rough, A14)
Very definite kind of bump		(Charcoal on smooth, A14)
A bit bumpy		(3H on rough, A15)
Gritty		(Charcoal on smooth, A9)
Quite bitty surface		(Crayon on smooth, A23)
Too rumbly		(Charcoal on smooth, A8)
Too vibrating		(Ball-point on smooth, A21)
Quite smooth and quite dry	DRY	(Charcoal on smooth, A3)
Too dry		(3H on rough, A21)
Feel drier		(Charcoal on rough, A23)
Dry		(Charcoal on smooth, A3)
Quite dry		(Charcoal on smooth, A3)
Quite crumbly		(Charcoal on smooth, A23)
Too chalk		(Ball-point on rough, A21)
Not oily		(Charcoal on smooth, A3)
Scratchy	SHARP/ SCRATCHY	(3H on smooth, A8); (Felt-tip on smooth, A22)
More scratchy		(Ball-point on rough, A22)
Very scratchy		(Charcoal on smooth, A6)
Too scratchy		(Charcoal on rough, A3, A6); (3H on rough, A8); (3H on smooth, A21)
A bit too scratchy		(Charcoal on rough, A3)
A bit scratchy		(Felt-tip on smooth, A23)
Slightly scratchy		(Ball-point on rough, A8)
Jerky		(3H pencil on rough, A9)
Very edgy		(Crayon on rough, A20)
Sharp		(3H on rough, A13)
Quite sharp		(3H on rough, A3)
Very sharp		(3H on rough, A7)
Not sharp enough		(3H on smooth, A18)
So harsh	HARSH	(3H on smooth, A 2)
Harsh		(2B on rough, A 2); (Charcoal on rough, A17)
Very harsh		(Ball-point on smooth, A18)
Too harsh		(3H on rough, A20)
Really harsh		(Ball-point on smooth, A17)
A little bit harsh		(3H on rough, A17)

Hard	HARD	(Ball-point on rough, A7); (Ball-point on smooth, A13); (Felt-tip on rough, A13); (3H pencil on smooth, A9); (Charcoal on smooth, A17)
Very hard		(3H on smooth, A8, A15); (2B on rough, A 2); (3H on rough, A5); (Ball-point on rough, A12)
Too hard		(3H on smooth, A24); (3H on rough, A20)
A bit hard		(Ball-point on smooth, A3)
Quite hard		(3H on smooth, A7)
Doesn't feel soft		(Ball-point on smooth, A2)
Solid		(Crayon on rough, A22)
Stiff	STIFF	(Charcoal on smooth, A10)
Quite stiff		(Ball-point on smooth, A10)
Stiff but quite a smooth		(Felt-tip on smooth, A10)
Rigid		(Roller-ball on rough, A13)
Really rigid		(3H on smooth, A 2)
So rigid and rough		(3H on rough, A 2)
More resistance		(Ball-point on rough, A23); (Felt-tip on rough, A23)
Less resistance		(2B on smooth, A9)
Slightly resistance but too resistance		(Graphite on rough, A9)
Have slight resistance		(Charcoal on smooth, A23)
Too resistance		(Ball-point on smooth, A9)
Resisting me from flowing		(Crayon on rough, A20)
Doesn't flow		(2B on rough, A 2)
Not slippery		(Roller-ball on rough, A5)
Stop and go, stop and go		(2B on rough, A17); (Felt-tip on smooth, A17)
Cannot move easily		(Felt-tip on rough, A18)
Cannot go very fast		(Crayon on smooth, A18)
A lot of drag		(Charcoal on rough, A10)
More drag		(Crayon on rough, A10)
Sticky	STICKY	(Roller-ball on smooth, A15); (2B on rough, A17); (Crayon on smooth, A17); (Crayon on rough, A17)
Slightly sticky		(Crayon on rough, A9)
Less sticky		(Crayon on smooth, A5)
A little bit sticky		(2B on smooth, A1)
A little bit more sticky		(Graphite on smooth, A1)
A little bit too sticky		(2B on rough, A14)
A bit sticky		(Crayon on smooth, A1)
A bit too sticky		(Felt-tip on rough, A8)
Very sticky		(Crayon on rough, A15)
More sticky		(Crayon on rough, A5)
Really sticky		(Felt-tip on rough, A8); (Crayon on smooth, A11)
A bit wet		(2B on rough, A6)
More viscous		(Roller-ball on rough, A6)
Slightly viscous		(Crayon on rough, A6)
More oily		(Graphite on smooth, A18)
Oily		(Ball-point on smooth, A8)
Not very greasy		(Crayon on rough, A3)
A bit greasy		(Graphite on smooth, A3)
More rubbery	RUBBERY	(2B on rough, A6)
Slightly rubbery		(2B on smooth, A8)
A bit too waxy	WAXY	(Graphite on smooth, A14)
Waxy		(Crayon on smooth, A23)
Really smooth		(2B on smooth, A 2); (Graphite on smooth, A20)

Very smooth	SMOOTH	(Roller-ball on rough, A1); (2B on smooth, A5); (2B on rough, A15); (Graphite on rough, A5, A23); (Graphite on smooth, A10, A18, A20); (Felt-tip on rough, A5); (Roller-ball on smooth, A20)
Very, very smooth		(2B on smooth, A23)
Too smooth		(Graphite on rough, A20); (Crayon on smooth, A20)
So smooth		(Crayon on rough, A2); (Roller-ball on smooth, A20)
Smooth		(2B on rough, A23); (Graphite on rough, A6, A16); (2B on smooth, A16, A21); (Roller-ball on smooth, A1, A4, A2, A7, A12, A13, A23); (Crayon on smooth, A2, A7); (Felt-tip on smooth, A1, A10); (Charcoal on smooth, A16); (Graphite on smooth, A8); (Charcoal on rough, A17)
Less smooth		(2B on rough, A3)
Quite smooth		(Charcoal on rough, A5); (Charcoal on smooth, A2, A3, A10); (Graphite on smooth, A3, A5); (3H on smooth, A5, A10); (Roller-ball on smooth, A5, A7, A11); (Roller-ball on rough, A5); (2B on smooth, A7, A16); (Graphite on rough, A7); (Crayon on smooth, A7, A10)
Very smooth and soft		(2B on smooth, A5)
Pretty smooth		(Roller-ball on smooth, A20)
Fairly smooth		(2B on smooth, A6)
Smoother		(2B on smooth, A9); (Graphite on smooth, A12, A13); (Felt-tip on smooth, A13); (Graphite on rough, A13); (Crayon on rough, A22); (Roller-ball on smooth, A22)
Much smoother		(2B on smooth, A12)
Less smooth		(Graphite on rough, A9)
Not very smooth		(Felt-tip on smooth, A3)
Not rubbery		(Felt-tip on smooth, A5)
Like velvet	VELVETY	(Charcoal on smooth, A23)
Soft	SOFT	(2B on rough, A10); (Crayon on smooth, A7); (Graphite on smooth, A2); (Charcoal on smooth, A5); (Graphite on rough, A23); (Roller-ball on rough, A13)
Soft flowing		(Graphite on smooth, A22)
Not very soft		(3H on smooth, A12)
Quite soft		(Graphite on smooth, A3)
More soft		(2B on rough, A7)
Softer		(2B on smooth, A22); (Graphite on smooth, A14)
Very soft		(Felt-tip on smooth, A2); (2B on smooth, A10); (Roller-ball on smooth, A2); (Crayon on smooth, A2); (2B on smooth, A11); (Graphite on smooth, A18); (Crayon on rough, A18)
Very, very soft		(Crayon on smooth, A2, A5)
Really soft		(2B on smooth, A2, A11)
Too soft		(3H on rough, A18)
Too spongy		(Ball-point pen on smooth, A14)
A little bit too much give		(Crayon on smooth, A14)
Not very soft & not very harsh		(Roller-ball on rough, A18)
Gliding	GLIDES	(2B on smooth, A 2)
Sliding		(Graphite on rough, A16)
So flowing	FLOWS	(Graphite on rough, A2)
Flows		(Roller-ball on smooth, A2); (Crayon on smooth, A2)
Flowing		(Graphite on smooth, A7); (Felt-tip on smooth, A10); (Charcoal on smooth, A10)
Quite flowing		(Roller-ball on smooth, A10)
Harsh but flowing		(Charcoal on smooth, A2)
A bit too fluid		(Graphite on rough, A22)
Quite fluid		(Charcoal on rough, A22)
So fluid		(Graphite on rough, A2)
Not fluid enough		(Felt-tip on smooth, A18)
Quite light		(Roller-ball on smooth, A23)
Can run as fast as I can		(Roller-ball on rough, A18)
It goes too fast		(Charcoal on smooth, A18)
It just goes		(Roller-ball on smooth, A17); (Charcoal on rough, A17)
Much more continuous		(Roller-ball on smooth, A17)

Flat	FLAT	(2B on smooth, A24)
Very flat		(Roller-ball on smooth, A24); (Crayon on smooth, A24); (Crayon on rough, A24)
Too flat		(Graphite on rough, A24); (Roller-ball on rough, A24)
A little bit too flat		(Felt-tip on rough, A24)
Not rumbling		(Graphite on smooth, A8)
Slippery	SLIPPERY	(Felt-tip on smooth, A5)
Very slick		(Crayon on rough, A22)